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POTENTIAL FOR ON-FARM BIOMASS GASIFICATION IN MONTANA

Prepared for
MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

POTENTIAL FOR ON-FARM BIOMASS GASIFICATION IN MONTANA

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Prepared for

Montana Department of Natural Resources and Conservation
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The following Milestone report has been prepared to document progress to date on a grant agreement dated April 1, 1985, between the Montana Department of Natural Resources and Conservation (DNRC) and the Civil and Agricultural Engineering Department at Montana State University. The DNRC grant number is RAE-85-1056.

Section 1. PURPOSE

This grant funds a study to lessen the state's reliance on fossil fuels pursuant to Title 90, Chapter 4, Part 1, MCA and the Administrative Rules adopted thereunder and to provide an engineering information base to evaluate the economic potential of biomass gasification in Montana.

Section 2. SCOPE OF THE PROJECT

The Grantee shall study the technical and economic feasibility of biomass gasification in Montana to meet the following objectives:

1.   Establish an information base on state-of-the-art gasification technology;

2.   Identify viable technical alternatives for agricultural gasification systems given Montana's unique environmental conditions and biomass fuels;

3.   Evaluate strategies and alternatives for introducing gasification technology into the state; and

4.   Promote adoption of gasification technology in Montana by distributing information developed through this project.

The study will specifically study agricultural biomass fuels
and agricultural applications of gasification technology and
will also generally address all other biomass fuels relevant
to Montana, including wood.

The Grantee shall perform the following tasks that have been
organized into a sequence of project milestones.

Section 3. SUMMARY OF PROGRESS ON MILESTONES

Date Completed

Milestone 1.	LITERATURE REVIEW AND GASIFICATION BIBLIOGRAPHY	November 22, 1985
Milestone 2.	GASIFICATION TECHNOLOGY ASSESSMENT	March 24, 1986
Milestone 3.	SMALL GRAIN INDUSTRY STUDY	October 1, 1986
Milestone 4.	CATTLE INDUSTRY REPORT	January 7, 1987
Milestone 5.	DEVELOPMENT OF A SITE SPECIFIC FEASIBILITY COMPUTER PROGRAM FOR BIOMASS GASIFICATION	June 6, 1987
Milestone 6.	POTENTIAL FOR ON-FARM BIOMASS GASIFICATION IN MONTANA	Octtober 30, 1987

Section 4. FINAL REPORT

Assemble the milestone report data and all supporting data that were prepared in compliance with and included in the preceding milestones and summarize the results in a comprehensive final project report.

Section 5. MILESTONE 6 REPORT:

POTENTIAL FOR ON-FARM BIOMASS
GASIFICATION IN MONTANA

1. Parties involved in this project were:

 a. The Civil and Agricultural Engineering Department, Montana State University, Bozeman, Montana 59717, (406) 994-2111.

 b. The Montana Department of Natural Resources and Conservation, Helena, Montana 59601-2301, (406) 444-6750.

2. The people to contact concerning this project are: Dr. W.E. Larsen, 205 Cobleigh Hall, Montana State University, Bozeman, Montana 59717, (406) 994-2111

3. The total budget for the project amounted to $27.811, to this date the amount used of this budget is $26,141.

5. This project was funded to research the use of renewable fuels to reduce Montana's dependence on conventional fuels. The study was centered on on-farm biomass gasification of wood and agricultural residues. The possible energy applications considered included irrigation pumping, grain drying, heating of livestock buildings, and cogeneration. Site specific models were developed and thier technical and economic feasibility assessed.

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ABSTRACT

The feasibility of using biomass gasification systems
on Montana farms was investigated for both technical and
economic merit. Large volumes of biomass are available and
they have the potential to replace conventional fuels.
Technically biomass can be used to replace conventional
fuels through gasification. Each gasification system must be
specifically designed for the site and the energy end-use
requirements. Ultimately a system's feasibility is
determined by its economics. The economic feasibility of a
gasification system is greatly controlled by the initial
expenditure, current fuel costs, feedstock costs, and yearly
usage. Most agricultural applications do not have enough use
per year to justify the capital expenditure. Also, current
fuel prices would have to increase greatly for a system to
become economically feasible. Cogeneration shows the best
economic potential, although the current electricity buyback
rate would have to increase and a long term use for the
generated heat would also be needed. These requirements are
not typical of most farming operations. This study shows
that gasification systems are very site specific, with even
the most ideal scenarios being noneconomical.

CHAPTER 1

BACKGROUND INFORMATION

Introduction

Today's agricultural community is very dependent on energy in one form or another. Conventional fossil fuels and electricity are used to power all types of farm machinery, heat buildings, heat water, pump irrigation water, and dry crops. To help lower energy costs and to reduce the farmer's dependency on non-renewable forms of energy, safe, efficient, and reliable forms of renewable energy need to be developed.

Many researchers have considered the possible use of gasification systems for on-farm applications in an attempt to use the renewable supply of biomass feedstocks. This thesis examines the technical and economic feasibility of gasification systems for use on Montana farms and ranches. The evaluation considers potential harvest techniques, handling, processing, and storage practices of biomass feedstocks as well as gasification and end-use applications suitable for Montana. The base knowledge for evaluating the total biomass gasification system from the collection process to the end-use application was accomplished through

an extensive literature review. The technical and economic concepts used in the analysis of on-farm gasification systems were obtained from this review. As a result this thesis contains many references from authors with expertise in the different areas of a biomass gasification system.

Several gasification techniques and gas filtering systems were evaluated along with possible end-use applications. The reason for evaluating these different components was to understand the advantages and disadvantages of each component and to piece together a system that would accomplish different on-farm tasks.

The requirements for gasification systems were determined for different applications along with possible system modifications. For example, a gasifier's feeding system often has to be modified to suit the physical properties of a feedstock, and internal combustion engines have to undergo certain modifications in order to be fueled with producer gas. Pollution control and electrical generation regulations that could possibly affect gasification systems in Montana were also reviewed.

An extensive study was conducted to determine the possible biomass feedstocks available for gasification. Wheat straw, barley straw, cattle manure, and wood showed the most promise for Montana. The harvest, handling, processing, and storage methods required by these feedstocks were then determined.

Several on-farm gasification scenarios were modeled to establish the economical feasibility of potential gasification systems. The scenarios were hypothetical cases dealing with irrigation pumping, grain drying, dairy barn heating, and cogeneration as end-use applications. Mobile applications, such as tractor/gasifier systems were not considered due to difficulty of using producer gas in this manner. Collection, transportation, processing, and storage costs were calculated to determine the cost ranges for each type of feedstock. The systems were then sized according to energy requirements and end-use application. The initial system costs, supply costs, repair and maintenance costs, and labor costs, etc. were determined and entered into a spreadsheet program to evaluate a given system's economic feasibility.

Survey of Different Biomass Conversion Alternatives

Different conversion technologies are available for using biomass for on-farm energy production. Among these are the production of methane through anaerobic digestion, fermentation of biomass to produce fuel alcohol, direct combustion to produce heat energy, and gasification to produce a combustible gas.

Anaerobic digestion is the process of breaking down organic biomass in the absence of oxygen, producing a gas composed primarily of methane and carbon dioxide. Livestock manure is an ideal biomass feedstock for anaerobic

digestion. A large amount of manure is required to produce gas, making anaerobic digestion suitable only for areas with large concentrations of manure. Possible sources would be dairy and feedlot operations. Unfortunately, anaerobic digesters are expensive to build and operate, therefore this technology may not have a large overall impact on on-farm energy generation (Boyette and McKusick 1986).

On-farm alcohol production also appears to be uneconomical because of the large initial expense, operation costs, and feedstock costs (Boyette and McKusick, 1986). Only in ideal cases where the grain feedstock is free, as with spoiled grain, is produced alcohol competitive with conventional fuels. Alcohol is finding some application as a gasoline octane improver but it depends on tax refunds to be economical.

Direct combustion of wood or agricultural biomass to produce heat is an on-farm energy alternative. The heat energy can be used in a boiler/generator set to produce electricity or for direct heating applications. Direct combustion has the disadvantage of being limited to heat production. It also must be managed carefully to prevent the production of large amounts of air polluting emissions.

Gasification appears to be the only conversion technology that can convert various types of feedstocks into a combustible gas suitable for either direct combustion or for fueling an internal combustion engine. Gasification also

has the advantage of producing a clean burning fuel that produces fewer emissions than direct combustion. The ability of gasification technology to accept various feedstocks and to produce a gas suitable for various applications may make it acceptable for widespread on-farm use.

Brief History of Gasification

The gasification process has been known for at least 200 years,and was applied to the gasification of peat and coal for steel making as early as 1843. At the turn of the century, gasification of coal was extensively used to produce gas for cooking and lighting. Around 1880 gas produced from gasifying coal was being used in internal combustion engines (Boyette and McKusick 1986).

Very little research on gasification was conducted until,in Europe, during World War II, the shortage of gasoline and diesel fuel triggered extensive research and use of gasification for fueling vehicles. Charcoal and wood gasifying units were used to fuel automobiles, heavy trucks, boats, and stationary engines.

In the 1970s, the energy crisis again prompted researchers to turn to gasificationbecause it showed a way to provide a potential renewable energy source. Many agricultural research groups began to explore the feasibility of gasifying wood, wood wastes, and agricultural residues for use on farms. On-farm applications include

grain drying, heating of livestock buildings and greenhouses, irrigation pumping, and electrical generation.

Today, research on gasification is still continuing with systems becoming more convenient and reliable. The conversion efficiency is also increasing. Research is also being directed towards creating small, simple, and rugged systems for use by third world countries--a potentially large market due to the high cost of fossil fuels.

CHAPTER 2

GASIFICATION TECHNOLOGY INFORMATION

Gasification Process

The aim of the gasification process is to transfer the energy of biomass feedstock to a gaseous fuel to be used in a variety of applications. This conversion process involves the combustion of the feedstock in a controlled environment that limits the amount of oxygen. In the gasification process the feedstock is heated, dried, and pyrolyzed to produce various gases, tars, and char. There are numerous reactions possible in biomass gasification, many of which are coupled. An extensive kinetic framework for carbon reactions in coal gasification was presented by Von Fredersdorff and Elliot (1963). Many of these reactions can also be applied to biomass feedstocks (table 1). By controlling the direction of gas flow, or the number of gasifying stages, a specific gasifier system can attempt to exploit some of the following reactions.

The composition of the produced gas is determined by the feedstock, oxygen supply, and process conditions such as pressure, temperature, residence time, and heat loss or heat input.

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Table 1. Gasification reactions.
==
Endothermic Carbon Reactions

Devolatilization C + heat -- CH_4 + condensible
                                 hydrocarbons + char

Steam-carbon C + H_2O + heat -- CO + H_2

Reverse Boudouard C + CO_2 + heat -- $2CO$

Exothermic Reactions

Oxidation C + O_2 -- CO_2 + heat

Hydrogasification C + $2H_2$ -- CH_4 + heat

Water Gas Shift H_2O + CO -- CO_2 + H_2 + heat

Methanation $3H_2$ + CO -- CH_4 + H_2O + heat

                     $4H_2$ + CO_2 -- CH_4 + $2H_2O$ + heat

A possible analysis of the gas obtained from a downdraft gasifier using air for gasification and wood as a feedstock would be as shown in table 2.

Table 2. Gas analysis.
        Boyette and McKusick 1986.
==
Constituent	Mole Percentage
H_2	16.63
CO	17.99
CH_4 (Methane)	1.94
C_2H_4 (Ethylene)	0.35
CO_2	12.86
N_2	50.19
Bal.	0.04

Carbon dioxide and oxygen are present in the end gas product because the chemical reactions are not being completed and also because nitrogen is introduced through the use of air as an oxygen supply. Steam may be a component of the gas depending on the moisture content of the feedstock. Although this example of producer gas composition is for a specific method of gasification and feedstock, the volume of each component is usually similar in proportion. The energy balance for this same gasifier is shown in figure 1.
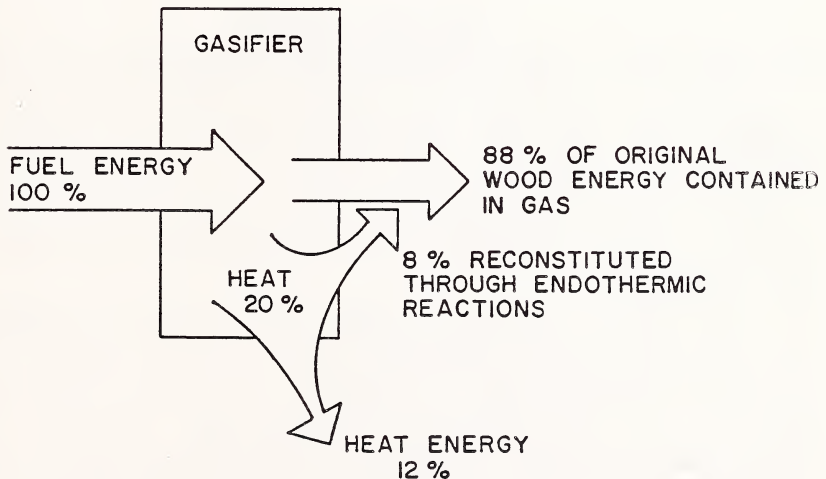
Figure 1. Gasification energy balance.
Boyette and McKusick 1986.

One basic distinction that can be found between different methods of gasification is the source of oxygen.

Using air as a source of oxygen in the gasification process is the simplest method but produces a low energy gas (94-188 Btu/ft^3) due to the presence of nitrogen in the air. Oxygen gasification, on the other hand, uses pure oxygen and produces a gas with a higher heating value (242-403 Btu/ft^3). The use of pure oxygen produces a gas much higher in carbon monoxide and hydrogen and in addition to heating and power applications, it can be used in the synthesis of methanol, ammonia, and other chemicals. Steam can also be used in combination with oxygen or by itself to produce a medium-heat-value gas.

Gasifier Designs

A wide variety of gasification methods is available, ranging in size and sophistication from simple units suitable for running small engines or boilers to large systems linked to plants for the manufacture of liquid fuels and chemicals.

The main component of a gasification system is the vertical closed tank or vessel referred to as the "gas generator", "gasifier", or "reactor". In this vessel. feedstock undergoes combustion and other chemical reactions involved in gasification. Openings are provided for feedstock loading, ash removal, ignition, introducing air for combustion, and gas discharge. Designs of different gas producers vary mainly by the method of introducing the combustion air and to the direction of the gas flow through

the reactor relative to the direction of fuel flow. Five
common categories which most gasifiers fall into are:

1. fixed-bed updraft gasifiers;

2. fixed-bed downdraft gasifiers;

3. fixed-bed crossdraft gasifiers;

4. moving-bed gasifiers; and

5. fluidized-bed gasifiers.

Fixed-bed Updraft Gasifiers

In a updraft gasifier (figure 2) feedstock is
introduced at the top of the gasifier and moves down through
the vessel under the force of gravity. Air inlets are placed
near the bottom where the combustion takes place and the gas
is produced. The gas leaves the gasifier by passing up
through the bed and exiting near the top of the reactor.
Because the gas flow is up through the pyrolysis zone, tars
are gasified and drawn off in the gas stream. This is not a
problem if the producer gas is going to be burned close to
the producer, but if it is to be piped any distance the gas
will cool and the tars will condense on the inside of the
pipe. If an updraft gas producer is used to produce gas for
an internal combustion engine, considerable care must be
taken to clean the gas.

Updraft gasification is characterized by the enlarged
hearth zone, which allows numerous ignition points for the
gasification process. This type of gasification is therefore

not sensitive to the choice of feedstock and is particularly
suitable to feedstocks with a low reaction response. The
large volume of the gasification zone offers a certain delay
in response to the fluctuations in gas demand. It also
requires a longer time for gasifier start-up and an initial
higher fuel consumption.
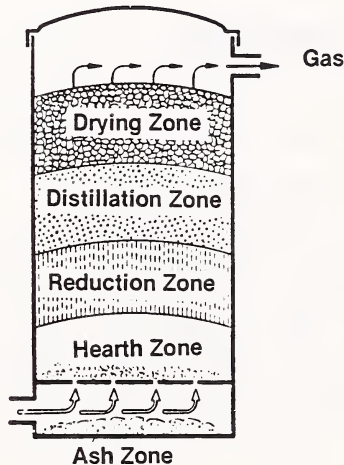
Figure 2. Fixed-bed updraft gasifier.
         Skov and Papworth 1980.

    In the updraft gasifier air is introduced below or from
inside the grate, causing the grate to be cooled. The cool
grate helps to deter slag formation. Heat from the grate
also preheats the air, thus improving gasification.

    Updraft gasifiers have a limit on the maximum size of
the reactor vessel, which restricts the maximum output to

about 48 MBtu/h. Gasifiers with diameters much larger than 10 ft may have difficulty in sustaining a uniform bed which, is essential for quality gas production.

Fixed-bed Downdraft Gasifiers

In a downdraft gasifier design (figure 3), the feedstock enters at the top, and air is introduced circumferentially through nozzles just above the reduction zone. The air draws all the gaseous feedstock components down into the hearth zone where they are exposed to high temperatures and to carbon where they undergo partial oxidization and partial dissociation. Therefore it is nearly impossible for steam, condensates, tars, and other volatiles to enter directly into the gas as in the updraft system.
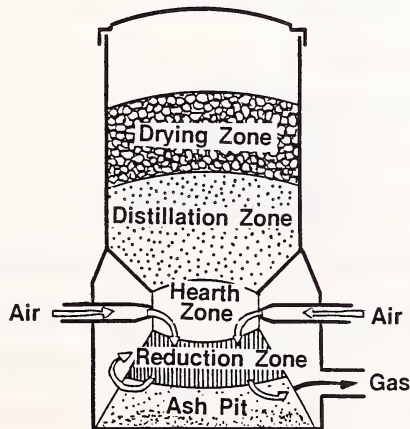
Figure 3. Fixed-bed downdraft gasifier.
        Skov and Papworth 1980.

Because downdraft gas producers have the potential to eliminate tars from the gas, they are considered the best gas producers for making engine quality gas, even when high tar feedstocks are used. This makes downdraft gas producers attractive for gasification of biomass feedstocks that tend to produce gas high in tars.

Downdraft systems have developed a characteristic venturi constriction of the hearth near the entry of the air stream. This constriction causes an increase in air velocity that produces an increase in temperature. This increase in temperature allows for a more complete conversion of tars into gaseous components. On the other hand, the constriction causes the walls of the hearth zone to heat up and the narrowed cross-section increases the resistance to air passage (Skov and Papworth 1980). This system is usually unsuitable for feedstocks with high ash content because the increased temperatures of the hearth zone will cause the ash to form slag and cause fouling.

Compared to the updraft method of gasification, the downdraft method uses a substantially smaller space for reactions and consequently accommodates fluctuations in gas demand more quickly. The start-up time is minimized. But the smaller reaction space requires uniform feedstock feeding and if irregularities occur, such as bridging, the already modest-sized reactive surface will be further diminished. Although the downdraft design may have some advantages over

the updraft design, it usually is more complex, and thus has a higher initial cost, as well as higher operation and maintenance costs.

Fixed-bed Crossdraft Gasifiers

In the crossdraft gasifier (figure 4) the feedstock enters through the top and the air enters through a small diameter nozzle at the side of the vessel. In this system the goal is to achieve a hearth zone of small volume but very high temperature, causing the tar components of the feedstock to completely gasify and the entire ash content to convert to slag. Using the small air nozzle, air velocities of up to 260 ft/s raise the temperature of the hearth zone core to about 2,000°F. The produced gases pass through a grate and out of the reactor.
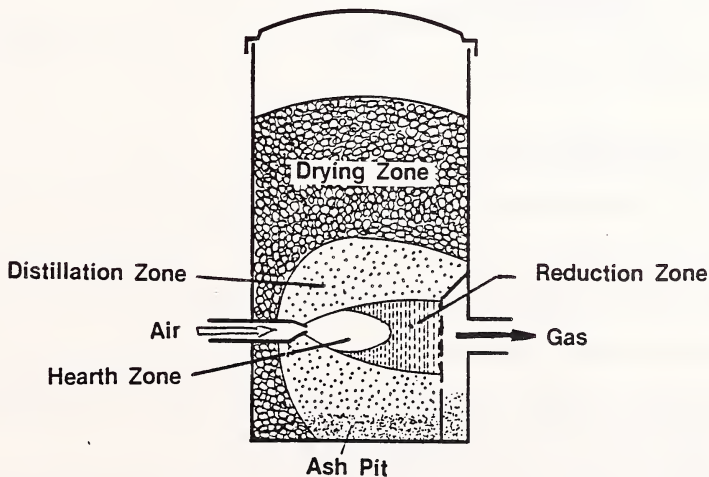
Figure 4. Fixed-bed crossdraft gasifier.
Skov and Papworth 1980.

This gasifier's central hearth zone has a different arrangement of zones. The distillation zone (or pyrolysis zone) is a spherical shape, with the drying zone around the outside serving as a heat shield for the reactor walls.

The small hearth zone enables the crossdraft system to quickly adjust to any fluctuations in gas demand. The system is flexible and needs little start-up time. But the system, because of the small hearth zone, requires smooth and uninterrupted feed of feedstock. Problems do arise with the formation of slag which affects gas quality and quantity.

Because tar dissociation is limited to the small hearth zone, the system is confined to feedstocks with low tar content. It is also desirable to use feedstocks with low ash content in order to keep the slag accumulation down. It is apparent that only the use of compatible feedstock types can assure long-term, trouble-free operation of crossdraft gasifiers.

Moving-bed Gasifiers

The moving-bed gasifier design (figure 5) is similar to that of a coal furnace. In this gasifier design the feedstock is fed through an airlock onto a moving grate. The combustion and gasification of the feedstock proceeds in proportions based on the process air flow. The produced gas is drawn off by an induced-draft fan.

The basic advantage of the moving-bed design is that it can be scaled up to large sizes because output is not

limited by the structural dynamics of the bed. The major
drawbacks of the moving-bed gasifier are its added
complexity, the horsepower associated with the moving grate,
and the limitation on feedstock caused by the grate design.
Fine feedstocks such as sawdust, and stringy fuels such as
straw are not suitable with the moving grate design. Because
of this limitation on the fuel type, the design is severely
restricted to one type of feedstock.
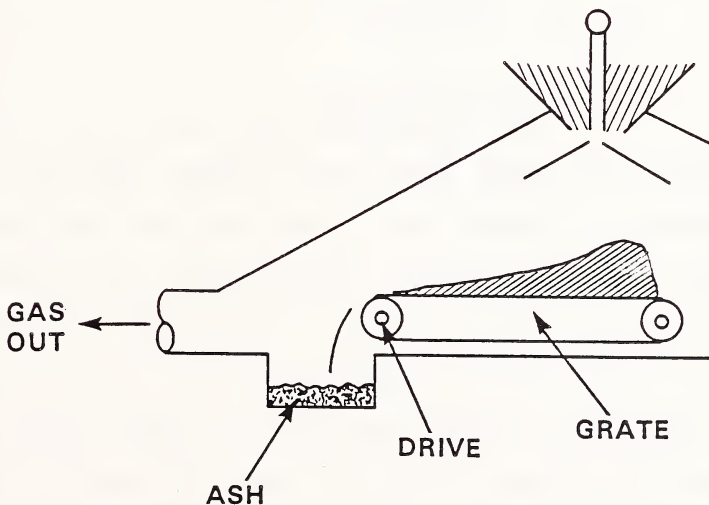
Figure 5. Moving-bed gasifier.
          F. C. Hart Associates Inc. 1983.

Fluidized-bed Gasifiers

Of all the types of gasifier systems the fluidized-bed
technology (figure 6) is the most recent development. In a
fluidized-bed gasifier the combustion and gasification of
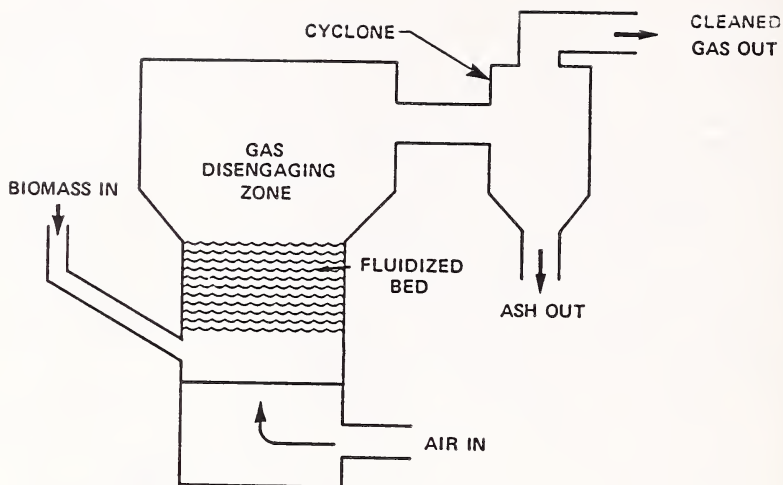
Figure 6. Fluidized-bed gasifier.
           F. C. Hart Associates Inc., 1983.

the feedstock takes place in a heated sand bed that is
agitated by an upward stream of air. The feedstock can be
injected into the gasifier using various methods, all of
which influence its residence time in the bed. There are
both top and bottom feed systems. Bottom feed systems in
fluidized beds are more analogous to downdraft systems,
because of their low tar production. Feeding the feedstock
in at the bottom allows it to travel the full length of the
bed, which increases its residence time. Tars are therefore
decomposed into other hydrocarbons to increase the carbon
conversion efficiency and the heating value of the produced
gas. The ash and unconverted carbon are removed from the
gasifier by the gas stream or withdrawn at the bottom of the
bed. If the ash is removed by the gas stream the filtering

system must be improved for any end-use application.

A broad range of operating conditions can be obtained in a fluidized-bed unit. Some of the parameters that can easily be changed include air velocity, operating pressure, type of bed material, and size of bed material. By controlling the air velocity, turbulence in the bed is varied to provide an accurate control of reaction temperatures. This agitation of the bed improves the efficiency of the conversion reactions and allows the use of feedstocks having wide variations in composition and particle size. The upper bed temperature limit is controlled by the feedstock's slag temperature. The basic advantage of the fluidized bed is its ability to accept many types of feedstocks, due to control of operating conditions and because it can be scaled up to large sizes (e.g. 190 MBtu/h) without much modification.

Fluidized beds have been used in a number of gasification studies involving biomass fuels. Some systems use a mixture of steam and air, or oxygen to fluidize the bed and give a gas with a higher heating value. Most systems use only air because it is the least expensive and the simplest to use.

Gas Cleaning and Cooling

The gas stream contains: gaseous components such as hydrogen, nitrogen, and water vapor; solid particles such as

ash, soot, and char; and semi-solids such as tars and pyrolitic oils. The gas stream exits the gasifier at temperatures ranging from 750 to 1,112°F.

Often the gas produced by the gasifier has to undergo some degree of cleaning and cooling, depending on the end-use application. Direct combustion of the producer gas in a secondary chamber or boiler needs little or no cleaning, while fueling an internal combustion engine requires intense cleaning and cooling. Using the producer gas in a boiler requires that only solid particles need to be removed from the gas stream.

The use of producer gas in an engine requires the removal of all the solid and semi-solid constituents of the gas stream. Solid particles such as soot and ash are hard and abrasive and can cause excessive wear within an engine. The semi-solid components such as tars tend to condense out of the gas steam onto valve stems causing them to stick, resulting in bent push rods and engine power loss. Cooling the produced gas is also important when using it in an engine. Cooled gas improves the volumetric efficiency of the engine. Generally a 18°F drop in gas temperature results in a 3% increase in power output (Boyette and McKusick 1986).

Removal of the harmful materials in the gas stream seems at first glance to be a very simple process, but it actually constitutes one of the most difficult tasks in gasification. The main reason for this is that the

impurities in the gas stream are many and varied and change from one system and feedstock to another. Filtering systems should be designed to remove the larger particles first, then the smaller particles, and lastly the tars and oils.

Most filtration devices can be classified as either in-line or off-line devices. Baghouse filters and packed beds are examples of in-line filters. These filters remove the impurities from the gas stream quite well but over time the contaminants build up on the face of the filter, blocking gas flow. For this reason, in-line filters require constant maintenance and are usually unacceptable for use in automated gasification systems. The main advantage to in-line filters is that they are easy to construct and are relatively inexpensive.

Off-line devices are filters that trap the impurities from the gas stream and carry them out of the gas flow. Filters such as cyclones, drop boxes, and liquid scrubbers may be classified as off-line devices. The advantage to these devices is that they can not be easily plugged and therefore can be left unattended for extended periods. The down side is that these filters can be expensive and add greatly to the cost of the system.

In the design and implementation of a filtering system the pressure drop through the filtering system should be kept to a minimum. Limiting pressure drop can be overdone since the degree of gas cleanup is proportional to the

pressure drop through the filtration system. If the resistance to gas flow is too great it may be impossible to start and operate the gasifier. The best approach is to filter the gas to the highest acceptable level without driving the pressure drop too high.

In summary, the design of a filtration system is dependent on the gasification system, feedstock, end-use application, and cost. The optimum filtration system balances both cleaning ability and system cost.

Producer Gas Use

The gas produced from a gasification process may be used in a variety of ways to produce energy (figure 7). Basically the gas is used to provide heat energy and/or mechanical shaft power.
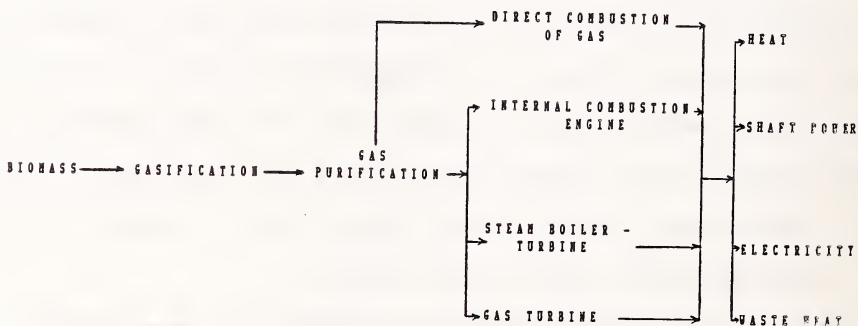
Figure 7. Alternate methods of producing energy from biomass gasification.
Adapted from LePori et al. 1983.

Direct Combustion of Producer Gas

The producer gas is often burned directly in a secondary chamber in order to obtain heat energy. This method provides a much cleaner combustion than does the direct combustion of the feedstock. Even if the gas contains tars, it is still a very clean burning fuel. This technique has been exploited by Payne et al. (1979) to provide heat directly through an air and exhaust-gas mixture for drying grain. Direct combustion of the producer gas has also been used through heat exchangers to heat greenhouses (Shaw et al. 1982).

Boilers

The gasifier can be directly coupled to a boiler to produce steam for use in manufacturing processes, heating, and to turn a steam turbine. The boiler must be close enough to the gasifier so that the tars do not condense out of the gas. The gas must be burned in properly designed burner nozzles because of the ash and tar content.

Internal Combustion Engines

The gas can be used in both spark ignition and diesel engines to produce mechanical shaft power without major modifications. To avoid engine wear and damage, tars, ash, and soot must be removed from the gas. The extent of the filtering system depends on the type of gasifier used and the type of feedstock gasified. A gas cooler is usually used

to cool the gas to increase the volumetric effiency of the engine. Many gasification/engine systems are being tested because internal combustion engines at the present time offer a potentially economical and available power source suitable for on-farm applications. These include stationary applications such as irrigation pumping and electricity generation or for mobile applications such as tractors and trucks. Stationary gas producers have the advantage that bulky, wet cleaners are not the drawback that they are with portable producers.

Gas Turbines

A gas turbine or combustion turbine consists of a compressor, combustor, and a turbine connected by a common shaft. Air is compressed, heated to high temperatures in the combustor, and then expanded in the turbine. The energy extracted from the gases by the turbine is used to drive the compressor and produce shaft power.

Gas turbines can use low Btu producer gas at the temperatures and pressures that exist when the gas flow exits the gasifier. This ability allows the turbine to obtain high conversion efficiencies. A gas turbine must be carefully selected to obtain optimum performance.

Steam Turbines

There are various steam turbine systems and configurations available to connect to a boiler-gasifier

arrangement. The steam turbines require high pressure steam
from the boiler to be expanded in the turbine. Steam turbine
systems are relatively more complex than other producer gas
applications. The fact that the technology is not widely
known by the farmer makes the system impractical for most
farm use.

Cogeneration

Combinations of the above methods for converting the
producer gas into usable energy are often used. These
combinations are termed cogeneration systems. Cogeneration
is defined as the sequential production of two or more forms
of output energy from the same input (Synergic Resources
Corporation 1983). Typically, cogeneration systems produce
electricity and thermal energy. The thermal energy may be in
the form of steam, hot water, or hot air. Mechanical
cogeneration systems are similar to electrical ones except
that a compressor, pump, or fan, etc. is connected to a
rotating shaft instead of an electrical generator.
Cogeneration systems tend to have high energy conversion
efficiencies because the waste heat lost in gasification,
combustion, and filtering, etc. is collected and used.

CHAPTER 3

BIOMASS SYSTEM REQUIREMENTS

Gasifier System Requirements

The successful development of a gasification system is a site-specific process involving the use of many components. An entire system can include feedstock collection, feedstock transportation, feedstock handling and preparation, gasification, gas clean-up, and use. In order for a gasification system to replace or compete with a conventional system it must satisfy two major requirements: reliability and economy.

A gasification system that is to be successfully operated on the farm must be reliable. During planting or harvest a farmer cannot afford to be troubled with a complicated and labor intensive gasification system. Secondly the system must be economically attractive--it should require a moderate initial investment by the farmer and have a relatively short pay back period. The system chosen should increase the overall efficiency of the farmer's operation in terms of time and economics.

There is a lot of flexibility in the types of systems available because various parts can be interchanged, to achieve the designed goals for a specific application. Thus

the key is to analyze the technical and economical aspects
of each component before selecting and adding it to the
system.

A gasification system's design must satisfy the user's
needs. The choice of a gasifier will depend on (F. C. Hart
Associates Inc. 1983):

1. the total amount of energy required;

2. the energy use profile;

3. the energy's end-use; and

4. the type of feedstock available.

The total amount of energy required to meet the needs
of an application should be determined, with some allowances
made for end-use inefficiencies and future expansion. The
design energy output from a gasifier is dependent on the
feedstock throughput and the heating value of the produced
gas. The ultimate selection of a gasifier may depend on
engineering and bed dynamic problems. The following table
can be used as an approximate example for scaling gasifier
sizes using wood. Table 3 does not include information for
crossdraft or moving-bed gasifiers because they are not a
common gasifier for biomass feedstocks.

The fluidized bed shows a very high throughput, because
of the improved contact between the gas flow and the
feedstock. In the updraft gasifier the gas flow rate is
limited because ash and feedstock particles will blow out
and channeling will occur in the bed. In the downdraft

gasifier the gas flow moves in the same direction as gravity; therefore higher flow rates can be achieved. But if the flow is too high, the pressure drop becomes too great and will result in channeling; unreacted gases and feedstock will pass through the grate.

Table 3. Relative gasifier throughput.
         R. Overend 1979.

REACTOR	THROUGHPUT OF DRY WOOD $(lb/ft^2/h)$
Updraft	20.5 - 41.0
Downdraft	59.4 - 100.3
Fluidized bed	307.2+

The energy use profile of a producer gas application should be considered when sizing a gasifier. The gas output from a gasifier is very slow to react to any throttling by limiting the feedstock input. When the biomass input is limited, the conversion efficiency and gas quality decrease. Therefore the end-use application's energy needs should be matched as closely as possible to the rated output of the gasifier in order to obtain optimum performance.

The quality of producer gas needed for different end-use applications varies for each application. When producer gas is used to fuel internal combustion engines the gas must be very clean in order to avoid excessive engine wear. Ideally feedstocks low in tar and ash content should be used

with a low-tar-producing gasifier (downdraft or fluidized bed). The more tar and ash in the gas stream, the greater the need for an efficient filtering system. If the produced gas is to be used in a boiler or for direct combustion the quality of the gas becomes less important.

System Modifications

All the different types of gasifiers have available various modifications that can be used to solve problems arising from use of a specific fuel or to adapt the produced gas to a certain application. These problems can include difficulties with feeding systems, slag formation, and the cleaning and cooling for fueling internal combustion engines.

Gasifiers can be operated in a batch or a continuous mode of operation. No continuous feeding system is used with batch operated gasifiers. When the gasifier needs to be replenished the gasifier is opened and biomass is added. This interferes with the controlled oxygen environment and disturbs the gasification process, which affects the quality of the produced gas momentarily. Batch gasification thus requires an operator to monitor and add the feedstock, adding to the cost of operation.

Many systems operate on a continuous basis for convenience, cost savings, and the need for an uninterrupted supply of quality gas. The feedstock is fed into the gasifier, usually by an auger type feeder controlled by

level sensors within the gasifier. Other feeders may be pneumatic, a hydraulic ram, or a vibratory conveyer. The feeder is fed through an airlock feeder from a feedstock hopper. The airlock feeder is used to lessen air entry into the gasifier and also acts as a measuring device. An auger feeder can act as an airlock for a moderately pressurized gasifier using fine material (Richey et al. 1983). Care has to be taken with an airlock not to jam the doors when wood and other coarse feedstocks are used.

A continuous feed system limits the problem of incomplete conversion and smoke entering the gas stream when the gasifier is opened for batch feeding. When a feeding system is properly adjusted for the gasifier, little monitoring is needed.

Slag formation is a problem when biomass fuels are used, especially with wheat straw and other agricultural biomass. Several methods have been used to discourage slag formation within the gasifier. Slag tends to form on areas of high temperature, like the grate of an updraft gasifier. Richey et al. (1982) solved this problem by using a hollow grate to feed air into the channel gasifier. This technique cooled the grate and greatly decreased slag formation on the grate and the preheated air helped the gasification process. Controlling the temperature on areas receiving high levels of heat (air nozzles, etc.) with water cooling is also helpful.

Problems are encountered with power loss and a need for machinery modifications when internal combustion engines are fueled with producer gas. When a spark ignition engine is converted to burn producer gas, the only major change is the replacement of the carburetor with a producer gas carburetor. The producer gas carburetor is used to mix the correct amount of air with the producer gas for proper combustion and consists of simple arrangements of butterfly valves. Because the energy content of the producer gas is lower than that of gasoline, the power produced by a spark ignition engine fueled with producer gas is 40 to 50% lower. A small increase in power can be gained by increasing the compression ratio and advancing the ignition timing by up to 20 degrees. Both of these adjustments are possible because the producer gas has a higher octane rating than gasoline. The power output of a diesel engine is also reduced when it is fueled with producer gas, and no simple adjustments can be made to overcome this problem.

To conserve diesel fuel and to improve the performance of an IC engine using producer gas, compression ignition engines can be converted to dual fuel operation. In this manner they will require about 15 to 20% of the normal amount of diesel fuel. This arrangement allows for the operation of IC engines without any major modifications. The producer gas is introduced with the combustion air into the intake manifold. The fuel injection pump introduces only a

small amount of diesel fuel into the engine to ignite the producer gas in the combustion chamber.

Studies have been conducted by Parke et al. (1981) and Ogunlowo et al. (1981) in the use of turbocharging and supercharging to increase the power of producer gas burning engines. Their investigations show that the power output of an internal combustion engine can be improved through the use of a turbocharger or supercharger.

Pollution Control Regulations

The gasification process involves the controlled combustion of a biomass feedstock yielding methane, carbon monoxide, hydrogen, nitric oxides, and particulates. Gasification has the potential to affect the environment through:

1. water pollution;

2. air pollution;
   - Sulfur oxides
   - Nitrogen oxides
   - Hydrocarbons
   - Particulates
   - Odor
   - Carbon monoxide

3. solid waste disposal; and

4. hazardous waste.

The Montana state government has implemented many regulations to minimize pollution. A permit from the Department of Health and Environmental Sciences (DHES), Air Quality Bureau is required for construction, installation, and operation of a gasification facility. Biomass facilities

must acquire an air quality permit for fuel burning equipment that has a heat input greater than 10 MBtu/h (liquid or gaseous fuel) or 5 MBtu/h (solid fuel). Other biomass facilities that can emit more than 25 ton/yr of any pollutant not regulated by the government must apply for an Air Quality Permit.

Table 4. Montana emission standards.
Renewable Technologies, Inc.

Pollutant	Emission Rate (tons/year)
Carbon Monoxide	100
Nitrogen Oxides	40
Sulfur Dioxide	40
Hydrogen Sulfide	10
Sulfuric Acid Mist	7
Reduced Sulfur Compounds	10
Total Reduced Sulfur	10
Particulate Matter	25
Ozone	40 (of volatile organic matter)
Trace Metals Lead Beryllium Mercury	0.6 0.0004 0.1
Asbestos	0.007
Vinyl Chloride	1
Fluorides	3

Table 4 shows air pollutants that are regulated by the
Montana state government when their minimum emission rates
are exceeded.

The city or county where a biomass gasification
facility is located may administer more stringent air
pollution standards than those set forth by the DHES. The
maximum allowable emission rate (lbs/MBtu) of particulate
matter for new biomass facilities is shown in figure 8.


```
MAXIMUM        1.00
PARTICU-       0.90
LATE           0.80
EMISSION--     0.70
POUNDS         0.60
PARTICULATE    0.50
PER MILLION
BTU HEAT       0.40
INPUT
               0.30

               0.20

               0.15

          1      10      100     1000     10,000
```

TOTAL INPUT--MILLIONS OF BTU'S PER HOUR
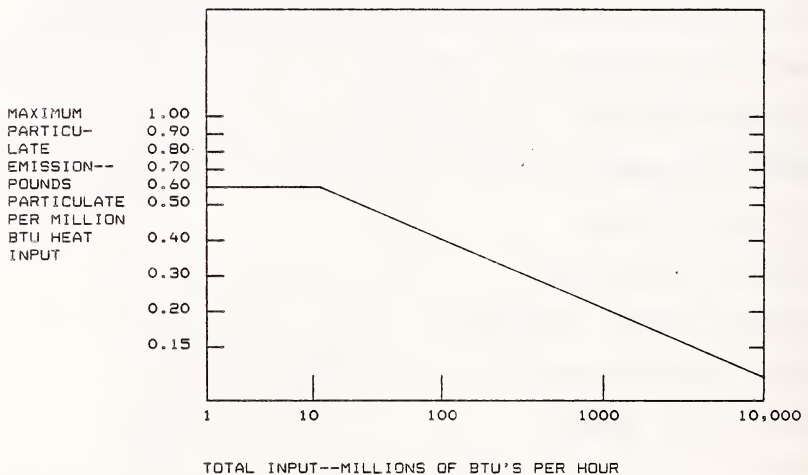
Figure 8. Maximum emission of particulates.
          Renewable Technologies, Inc.

All biomass energy projects that discharge liquid or
solid pollutants into surface or ground waters must obtain a
permit to do so from the DHES. There are no exceptions for
quality and quantity of the discharge. Biomass facilities

are subject to the state's effluent standards to ensure water quality.

The subject of waste management covers both solid waste (non-hazardous) and hazardous waste disposal. Solid wastes include garbage, hazardous wastes, ashes, and industrial by-product. Generators of solid waste must dispose of that waste at a licensed disposal facility, or if the generating facility owns or leases 5 acres or more of land a private site can be set up. Hazardous waste is a waste that can contribute to mortality or serious illness. A waste is classified as hazardous if it is listed by the Environmental Protection Agency as such. The storage and transportation of hazardous wastes is strictly monitored by the DHES. Violators of hazardous waste laws may be subject to civil and criminal penalties.

Under normal conditions, biomass facilities should not generate any hazardous wastes. However, products such as solvents used in operation and maintenance can be classified as hazardous. For more information on pollution standards and obtaining permits refer to "Montana's Bioenergy Project Permitting Guide" obtainable from the Montana Department of Natural Resources and Conservation.

Federal Small Power Producers Regulations

On November 9, 1978, the Carter Administration signed into law the National Energy Act. The National Energy Act included three major parts, the Public Utility Regulatory

Policies Act, the Fuel Use Act, and the Natural Gas Policy Act. These parts cover restrictions on fuel use, tax incentives for project development, and incentives for small power producers and cogenerators.

The Public Utility Regulatory Policies Act of 1978 (PURPA) basically allowed the Federal Energy Regulatory Commission (FERC) to remove both regulatory and economic obstacles for small power production and cogeneration facilities using renewable fuels. The FERC was authorized to require electric utilities to pay reasonable rates to cogeneration and small power facilities for generated power. The buy-back rates paid by the utilities are based on the avoided costs and not the cost of service. The avoided costs are defined as all the expenditures that the utility would save by not generating or purchasing the equivalent amount of power. The avoidance cost is set by each state's regulatory commission and the buy-back rate must not exceed this set cost. Power utilities that existed before the enactment of PURPA can pay a lower rate, as long as the rate encourages cogeneration. The PURPA also required electric utilities to provide non-discriminatory electric service to small power and cogeneration facilities. Finally, PURPA exempted all cogeneration and certain small power producing facilities from state regulations regarding utility rates and most federal regulations under the Federal Power Act and the Public Utility Holding Act.

The PURPA defines a cogeneration facility as a facility that produces electrical energy and other forms of useful energy. Small power production facilities are defined as facilities having a capacity of 80 MW or less and fueled by biomass, wastes, or other renewable sources to produce electricity.

The following is a summary of PURPA regulations (Synergic Resources Corporation):

1. New qualifying facilities are to be paid full avoided cost for buy-back rates.

2. The state regulatory commission and non-regulated utilities are to establish the rates.

3. The simultaneous purchase and sale of power between the utility and facility is allowed.

4. Stand-by power must be provided at non-discriminatory rates.

5. All qualifying facilities are exempt from federal and state regulations concerning rates and financial organization.

CHAPTER 4

POTENTIAL FOR GASIFICATION IN MONTANA

Montana's Agricultural Energy Consumption

In 1985, there were 23,600 farms and ranches in Montana covering approximately 60,000,000 acres. Cattle were raised on 52,000,000 of these acres with the balance being used to grow crops. A breakdown of Montana's agricultural receipts is shown in figure 9.

MONTANA'S AGRICULTURAL INCOME
1985

WHEAT (30.2%)

CATTLE (46.1%)

BARLEY (9.5%)

OTHER GRAINS (7.1%)

OTHER LIVESTOCK (7.1%)
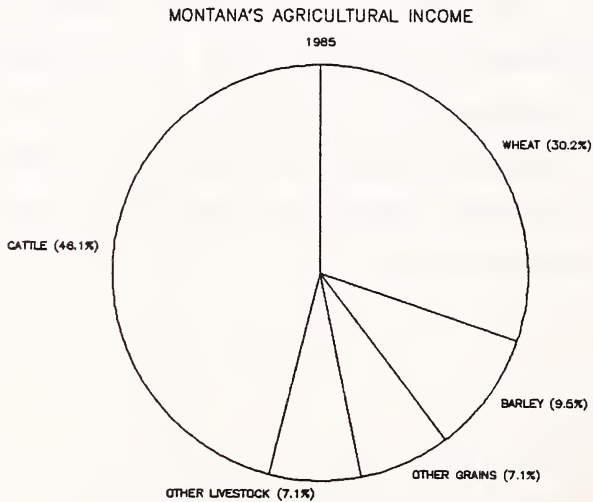
Figure 9. Montana's agricultural income, 1985.
Montana Agricultural Statistics Service.

The cost to produce these crops and livestock varies significantly from farm to farm, but in general the cost is high. A major contributing factor to the high cost of production is energy costs. During 1982 Montana farmers and ranchers spent $157,696,000 on energy used to operate vehicles, equipment, homes, buildings, and irrigation systems. A general breakdown on how conventional fuels were used on the farm in 1982 is shown in figure 10.

MONTANA AGRICULTURE ENERGY EXPENDITURES
1982
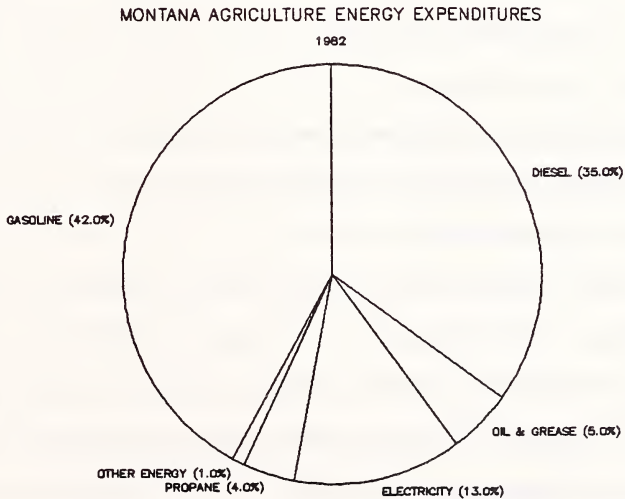
Figure 10. Montana's 1982 agricultural energy expenditures. Source: Saving Energy on Montana Farms and Ranches, 1987.

Agriculture in Montana uses a large amount of energy for farming operations. Figure 10 shows that the majority of energy expenditures involve gasoline and diesel fuel for

vehicle operation. The remaining energy expenditures, except for motor oil and grease, could potentially be replaced by gasification of agricultural and wood residues.

Possible End Use Applications In Montana

The gas produced from a gasification process may be used to provide heat energy and/or mechanical shaft power. In agriculture, gasification systems would be ideal for both the small grain and livestock sectors. The possible end-use applications in the agriculture industry are:

1. irrigation pumping;
2. grain drying;
3. heating of livestock buildings;
4. electrical power generation; and
5. cogeneration.

Crop drying is a very energy intensive agricultural operation. Large amounts of propane (LPG) are used annually in the United States for this purpose. A gasifier could be used to provide all the heat requirements of a grain drying system. Approximately 2,000 Btu of heat are required to remove 1 lb of water from the grain. Drying, in a 10-hour day, 1,200 bushels of grain with an initial moisture content of 18% (w.b.) to 13% requires approximately 950,000 Btu/h of heat. The produced gas can be burned and fed directly into the drying system with minimal contamination of the grain. This type of end-use application may only need a filtering system capable of filtering out particulates. The tars

contained in the gas stream are burned along with the producer gas, producing few emissions.

Using internal combustion engines for generating mechanical power for irrigation pumping or electrical generation is a possible on-farm end-use application.

Two types of electrical generators can be used on the farm: induction and synchronous. Induction generators are basically electric motors that are driven faster than their rated or synchronous speed. When the generator is driven above the synchronous speed, it draws excitation current from the utility main, and the power generated is then fed back to the grid. The power frequency generated is not dependent on the generator's rotor speed but on the incoming frequency of the grid. This allows the induction generator output to be synchronized with the utility's grid power. Although switching gear is required to interface the generator to the power grid, the apparatus is not as complicated and expensive as that required for a synchronous generator. The draw-back to induction generators is that without this excitation current from the utility the generating system can not serve as a back-up power supply in an emergency.

The synchronous generator is the type used in on-farm emergency generator sets. A synchronous generator does not require an excitation current to operate. The disadvantage to synchronous generators is that the frequency of the

output is directly dependent on the rotational speed of the generator. Maintaining the RPM of the generator exactly at the required speed is nearly impossible when using a producer gas fueled engine because of the fluctuations in the gasifier's output and the governor characteristics of an internal combustion engine. If the generated electricity is to be used for resistive loads the output frequency tolerance is large. On the other hand, if the electricity is to power induction motors, the frequency tolerance narrows considerably. When a synchronous generator produces power for sale to the utilities extreme care must be taken to match the power frequencies. To do this, expensive, complicated equipment is needed to synchronize the frequencies and to monitor the generator output so the generator can be disconnected if needed.

For on-farm power generation, induction generators are better suited for the sale of electricity than synchronous generators, but are not adequate for emergency or remote power production.

On-farm gasification/cogeneration systems would probably produce electrical and heat energy. The electrical power may be produced by engine/generator sets using induction or synchronous technology. The choice of generation is dependent not only on the site but also the needs of the user. The thermal energy may be in the form of steam, hot water, or hot air. The heat will be produced by

heat exchangers collecting waste heat from the system, increasing the conversion efficiency of the system to 50 or 60%. The size of the gasification system may be dictated by the amount of heat or by the electrical energy needed.

CHAPTER 5

BIOMASS FEEDSTOCKS

Gasification systems suitable for applications in Montana are in part limited by the biomass feedstock available in the facilities immediate area. Biomass materials can be classified into five major categories (Ebeling and Jenkins 1983):

1. field crops;

2. orchard prunings (fruit and nut crop prunings);

3. forest residues (logging slash and mill residues);

4. food and fiber processing residues; and

5. livestock residues (confinement animal manures).

In Montana, field crops and forest residues provide the bulk of biomass available for gasification, although livestock residues may be feasible in certain areas. Additional biomass resource information can be obtained through the State of Montana Department of Natural Resources and Conservation.

Small Grain Inventory

Of the solar energy incident upon the earth's atmosphere about 0.02% is transformed through photosynthesis

into carbohydrates. On a global basis this amounts to an annual production of 110,000,000,000 tons of plant biomass and approximately 5 times the current energy consumption of the world. Agriculture itself is a source of considerable quantities of biomass in the forms of field crop residues and crop processing wastes. In the United States the annual production of biomass from crop residues such as barley, corn, cotton, oats, rice, rye, sorghum, soybeans, and wheat is estimated at 428,000,000 tons.

In Montana, agriculture is the most important industry. Agriculture provides about one-third of the total receipts of Montana's primary industries. Of this one-third, approximately 41% is contributed through the sales of small grains. The types of small grains grown in Montana in any sizable amount include:

1. wheat - winter, hard spring, and durum;
2. barley; and
3. oats.

Wheat is commonly grown in Montana, with both winter, spring, and durum varieties comprising the majority of the small grain acreage. Barley is the next small grain crop that is grown in any significant amount. The amount of barley produced in 1984 was estimated at approximately 1,418,000 tons, while the total wheat production was about 3,140,000 tons. Oats were the third most commonly grown crop in Montana for the 1984 crop year, with approximately 66,000

tons produced. Farmers who grow oats generally do so for livestock feed. The oat straw is usually baled and also used for feed. Because of oat straw's value for feed and its lack of availability in large amounts (as compared to wheat and barley), use as a biomass feedstock for energy production is probably unlikely.

Small Grain Inventory by County

Each county in Montana has varying climatic, soil, and terrain conditions that tend to determine the types and quantities of crops grown. Figures 11 through 15 show the distribution (bushels) and rankings by counties of the different crops for the 1984 crop year. From these figures it can be concluded that the counties in the northcentral, northeast, central and southeast districts produce the bulk of Montana's small grains. Actual data on acres seeded, acres harvested, yield per acre, and the total production for each county for the 1984 crop year can be seen in Appendix A. The amount of accessible biomass feedstock and its distribution determines in part the size of the gasification system. Estimates on crop residue yields are based on grain yield and are shown in table 5.

The calculated amount of biomass available is said to be 95% of the plant or the above ground portion. Actual collection of all the above ground biomass may be infeasible because of equipment limitations or from the standpoint of erosion control, nutrient loss, and moisture trapping.
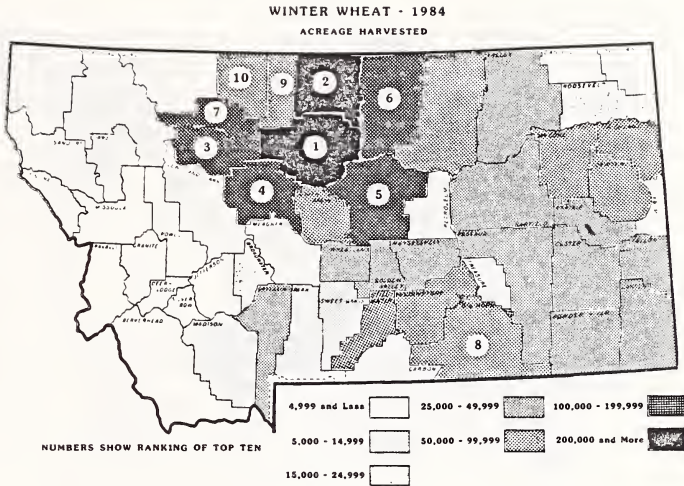
Figure 11. Winter wheat, 1984.
        Montana Agricultural Statistics Vol. XXII, 1985.
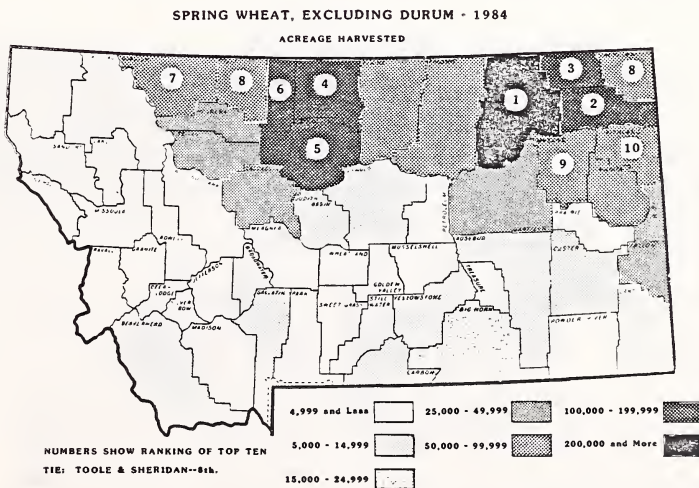
Figure 12. Spring wheat, 1984.
        Montana Agricultural Statistics Vol. XXII, 1985.

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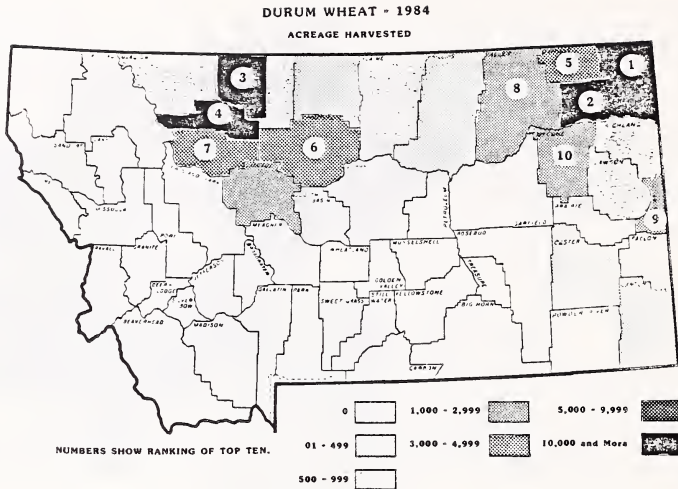
Figure 13. Durum wheat, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.
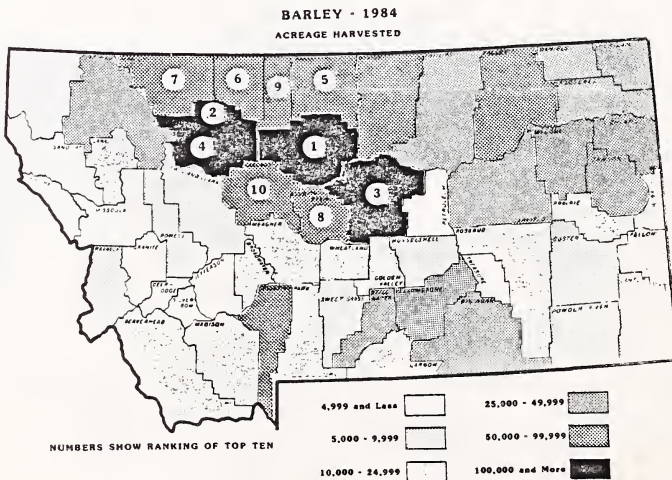
Figure 14. Barley, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.
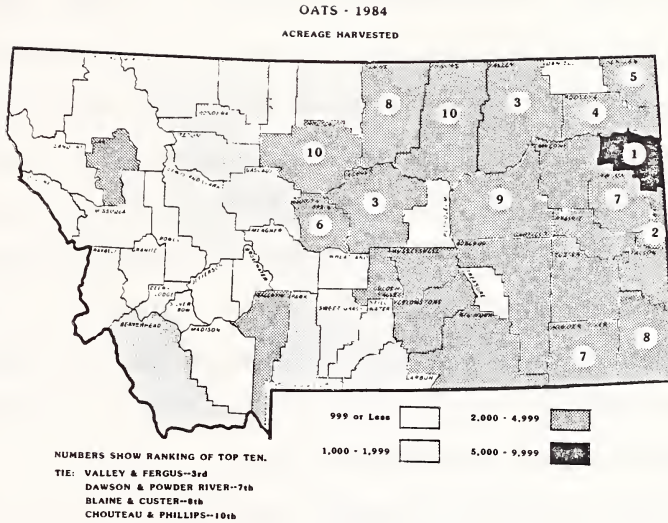
Figure 15. Oats, 1984.
Montana Agricultural Statistics Vol. XXII, 1985.

Table 5. Montana grain crop residues conversion.
Synergic Resources Corporation, 1983.

Crop	Unit Weight (lb/bu)	Straw/Grain Ratio	Straw Weight (lb/bu of grain)	Availability
Winter Wheat	60	1.3	78	95%
Spring Wheat	60	1.3	78	95%
Barley	48	1.1	52.8	95%
Oats	34	1.6	54.4	95%

Koelsch et al. (1977) determined in field tests that the three machines commonly used to gather straw, small

square baler, large round baler, and the self-loading stack-
forming wagon collected respectively just 15%, 25%, and 33%
of the available straw after combining. The straw was left
in windrows behind the combine with the straw spreaders and
choppers disconnected. The U.S. Department of Agriculture
estimates that roughly 35% of the crop residues can be
removed safely under conventional tillage practices without
any detrimental effects.

If we assume that 3,140,000 tons of wheat and 1,418,000
tons of barley (1984 crop year) were grown in Montana the
potential biomass harvest could be:

```
Wheat Straw = (3,140,000 ton grain)
            * (1.3 ton straw/ton grain)
            * (25%/100 availability)
            = 1,020,500 ton straw

Barley Straw = (1,418,000 ton grain)
             * (1.1 ton straw/ton grain)
             * (25%/100 availability)
             = 389,950 ton straw
```

For on-farm use of crop residue biomass, a site
specific analysis of the feedstock source can be easily
done. The maximum size of a farm scale gasifier is usually
determined by the amount of biomass available. When the
scale of the facility increases beyond the farm scale,
determination of the size and availability of the biomass
resource becomes more difficult. The quantity, quality, and
distribution of the feedstock become very important in the
size and feasibility of the overall system. Generally, using
county-wide analysis of the biomass supply is not good

enough for large scale facilities and a more intense survey is needed (Jenkins and Sumner 1985).

Variation in production of small grain crops is mainly due to changes in grain prices and the variation in the weather. The previous year's grain prices and future forecasts are usually the factors a farmer uses to decide on the type of crop and the quantity to plant. The weather then determines the final crop yield. The farmer is said to be at the mercy of the weather. Figures 16 and 17 show the variations in crop productions over the 1975-1984 crop years. The figures give an excellent indication of the variability of production caused by grain prices. Compared with the actual prices received by the farmer (Figure 18) the general decline in prices causes a decline in production.
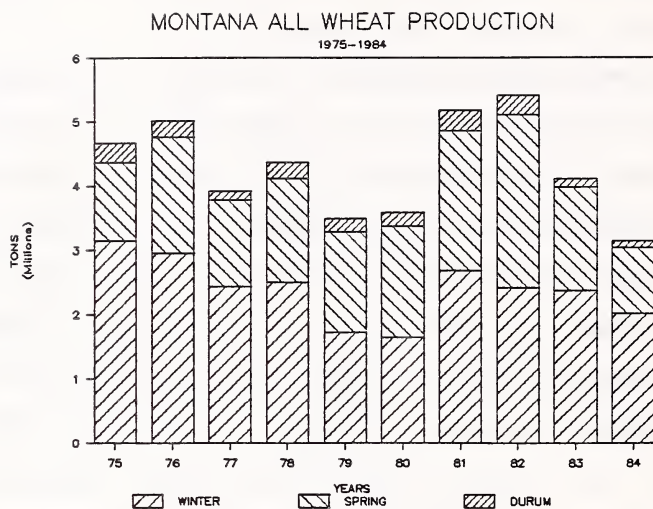
Figure 16. Montana all wheat production, 1975-1984.
            Montana Agricultural Statistics Vol. XXII, 1985.
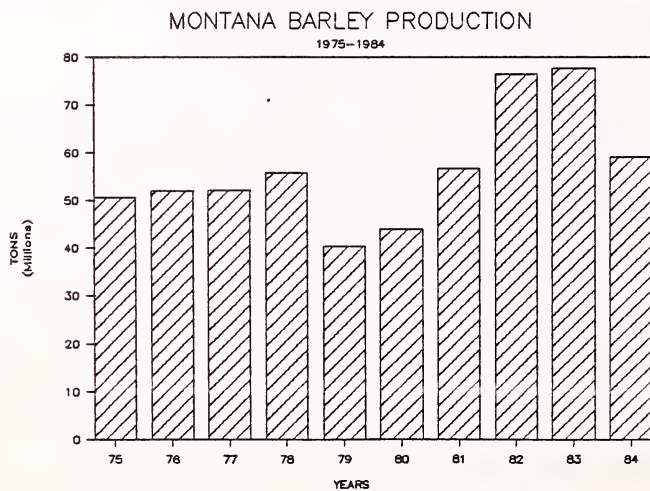
Figure 17. Montana barley production 1975-1984.
            Montana Agricultural Statistics Vol. XXII, 1985.

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PRICES RECEIVED BY MONTANA FARMERS
ANNUAL AVG. $/TON (1975–1984)
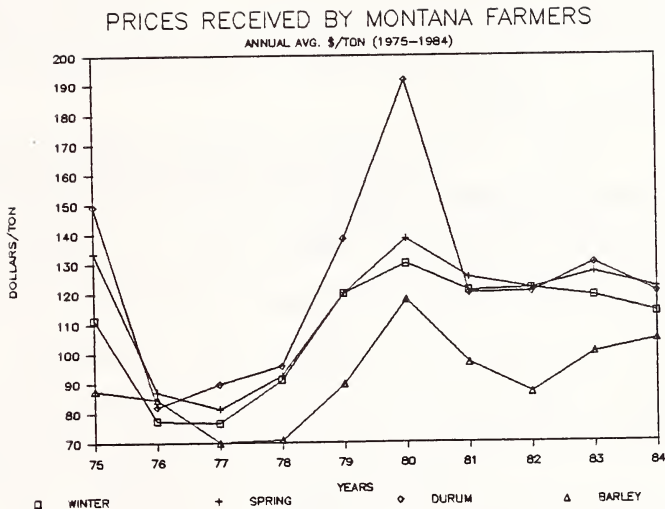
Figure 18. Prices received by Montana farmers.
          Data taken from Montana Agricultural Statistics
          Vol. XXII, 1985.

Animal Wastes Inventory

Livestock wastes, which in Montana are primarily cattle
wastes, provide a potential source for energy through
gasification. The value of animal wastes for use as biomass
feedstock is due to their availability in substantial
amounts in concentrated areas. The main requirement for
using manure as a biomass source is that it must be free of
contaminants such as dirt. The presence of dirt in the
manure raises the ash content of the fuel. When gasified,
this ash can increase the chance that the gasifier will
foul, which will affect the quantity and quality of the

producer gas. Even if the gasifier does not foul, the increased ash level will be a greater burden on the filtering system, requiring increased maintenance or possibly redesign.

Another requirement to make manure available as a feedstock is that cattle need to be confined in areas such as feedlots and dairy barns. This is necessary in order to concentrate wastes and keep collection costs low. Dairy barns are an ideal location for collection of dirt-free wastes. Dairy barns use various manure collection schemes such as drag chain gutter cleaners or slatted floors. The collected manure is usually stored in a pit or pile for disposal on fields or alternatively for use in a gasifier.

The main problem with the use of manure as a biomass feedstock is that fresh manure contains approximately 88% moisture. The manure must be dried before it can be gasified. This process requires a large amount of heat energy which decreases the net energy production of the system.

In 1985, Montana had a total of 2,960,000 head of cattle and calves. Approximately 1,513,000 were beef cows and 27,000 dairy cows. Assuming that dairy farms provide an ideal situation for the collection of manure, the potential amount of dried biomass could be:

```
Manure = (27,000 cows) * (10 lb dry manure/day/cow) *
         (365 day/yr) * (50%/100 availability) /
         (2,000 lb/ton)
       = 24,638 ton/yr
```

Note: This assumes that the average dairy cow weighs 1,000
lb, and produces 10 lb of dry matter per day (table 6), and
that only 50% of the manure can be collected.

Table 6. Cattle waste production per day.
         Pennsylvania State University.
===
| Animal | Pounds of Waste[1]/Day | |
| | Wet | Dry |

| Dairy Cow | 85 | 10 |
| Beef Cow | 60 | 7 |
----

[1] lb of waste / 1000 lb of animal weight.

The variation in manure production is dependent on the
cattle population. The cattle population, especially beef
cattle, in turn depends on both market value and feed
supply. Figure 19 shows directly the relation between the
number of cattle and their market price. Dairy cattle
numbers are also dependent on milk prices and production
quotas.
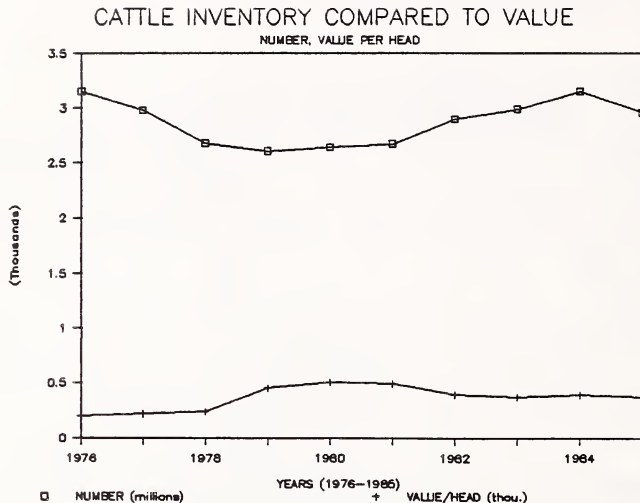
Figure 19. Cattle inventory in Montana compared with market value.
Data taken from Montana Agricultural Statistics Vol. XXII, 1985.

Wood and Wood Wastes Inventory

The forests of Montana cover approximately 22% of the state's land area, amounting to 20,262,200 acres. Of this 20,262,200 acres, only 14,331,800 acres are considered to be productive timber land. Using the Continental Divide as a reference point, over one-half of the forest area lies to the west. West of the Divide, the land base is 80% forested, while the area east of the Divide comprises 83% of Montana's land base but is only 13% forested.
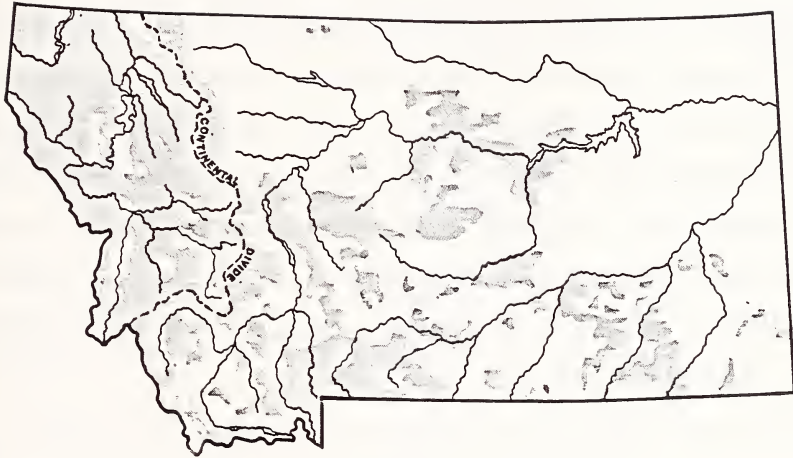
Figure 20. Forest distribution in Montana.
          A. W. Green et al. 1985.

The western side of the Divide is heavily forested
because the high mountain ranges trigger the release of
moisture from the westerly air flows. The drier climate east
of the Divide limits the forests to higher elevations. This
causes the forests to be fairly patchy and widely scattered.

Montana forests contain 27 species of trees; 17 are
conifers and 10 are hardwoods (see appendix B). These
species may grow intermixed or in pure stands. The type of
species growing in an environment greatly depends on the
site's elevation, yearly moisture, and soil characteristics.
The major tree species grow over a range of environmental
conditions, and some become the climax vegetation for a
specific environment.

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Montana is divided into five major climax forest zones, as shown in figure 20. The dominant species in each zone are shown and include; larch, lodgepole pine, ponderosa pine, douglas-fir, white pine, and spruce-fir. Figure 21 associates the general land type and elevation with the forest zone. In about 64% of the forests in Montana, the dominant species are douglas-fir and lodgepole pine. Adding ponderosa pine and fir-spruce zones brings the total to 93% of the forest area.
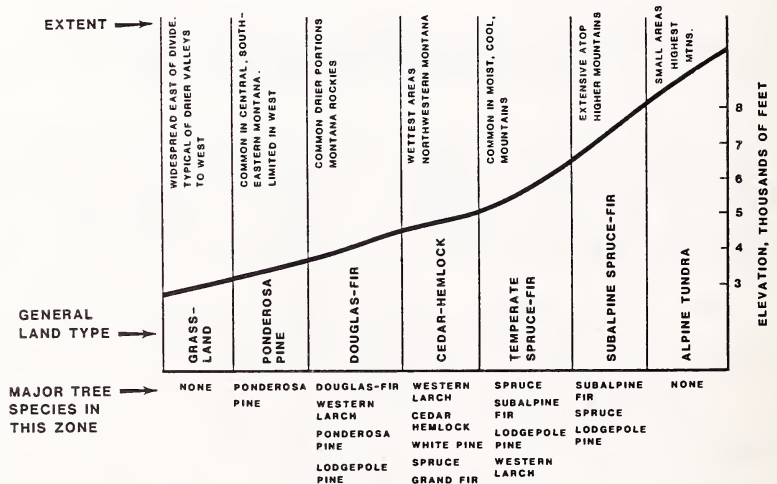
Figure 21. Forest zones of Montana.
A. W. Green et al. 1985.

Approximately 74% of Montana's forest land is publicly owned, with 68% federally regulated while the remaining is owned privately or by the forest industry (table 7).

Table 7. Forest ownership in Montana.
        Green et al. 1985.
==
Owner Group	Area (1000 acres)	Percent of Total
Public		
Forest Service	13,817.2	68
Other Public	1,053.4	6
	--------	--
Total	14.870.6	74
Private	5,355.4	26
	========	===
Total	20,226.0	100

The net volume of growing stock and sawtimber in Montana during 1980 is summarized in table 8.

Table 8. Net volume of growing stock and sawtimber on
        commercial timberland in Montana, 1980.
        A. W. Green et al. 1985.
==
Growing Stock (million cubic feet)

Owner Group	Softwood	Hardwood	Total
Public			
Forest Service	18,089.5	46.0	18,135.5
Other Public	1,222.3	44.5	1,266.8
	--------	----	--------
Total	19,311.8	90.5	19.402.3
Private	6,436.9	326.8	6,736.7
	========	=====	========
Total	25,748.7	417.3	26,166.0

Forest residue is a possible source of biomass feedstock for gasification. These residues include logging residues, thinning residues, standing residues, and clearing residues. Logging residues are made up of the unused tops,

limbs, poor quality logs, and brush left over from the harvest operation. The amount of logging residue may range from 10 to 20% of the standing tree, with hardwoods generally producing more residue than softwoods. Standing residues are trees that are unsuitable for timber or dead trees that are dried and cracked. The forest residue is generally left in the forest to decay and if collection costs are minimal, it may be a valuable feedstock.

An average of 96,000,000 ft^3 of timber is harvested annually in Montana. The total volume of logging residues generated from harvesting the timber is estimated at 838,000 bone dry tons. Due to economics, only an estimated 230,000 dry tons of logging residue is suitable for fuel usage annually in Montana (Combes 1983).

The total residue available for biomass and other products from pole timber, cull trees, dead trees, and down trees on commercial forest land of the national forests is estimated at 1,031,300,000 ft^3. At the present time, due to poor collection economics, only about 45% of this residue is accessible, amounting to a total of 56,000,000 tons of dry wood (Combes 1983).

Another important source of wood for gasification is wood wastes left over from both primary and secondary processing. Over one-half the volume in logs delivered to sawmills ends up as wood wastes. Mill wastes are in several forms: coarse, fines, and bark. The coarse materials are in

the form of slabs, edgings and trimmings, and peeler cores; the fines are made up of sawdust and shavings.

Generally, the waste wood creates a disposal problem at a mill. It is usually burned in tepee burners or just piled up. In some cases the wood wastes are utilized in the pulp and paper industry for feedstock or fuel. Most of the smaller mills have no market for the wastes and thus the wastes are a disposal problem.

The amount of forest residue available is fairly variable in Montana. It is directly connected to the amount of timber harvested, which in turn is dependent on lumber demand and the interest rate charged on home mortgages.

Properties of Biomass

Biomass includes a wide variety of organic material different in both chemical and physical properties. Defining these properties for each type of biomass is essential for the development and evaluation of a gasification system.

Wood gasification systems have been in use since World War II and as a result the technology for wood is well known. As compared to wood, very little research has been conducted on gasifying crop and livestock residues. It is usually assumed that the thermochemical reactions for crop residue are the same as for wood or fossil fuels. This assumption is wrong because of the differences in chemical and physical composition. Crop and livestock residues are

high in ash and silica which can cause problems in gasification. Residues such as straw often require the feeding system to be modified to allow for proper operation.

Chemical Properties

The chemical properties of a feedstock can be determined through proximate or ultimate analysis. Proximate analysis can identify the amount of moisture, fixed carbon, ash, and other components in a fuel. General gasification characteristics can be determined from this analysis. The ash content of the feedstock is important because it affects the reaction temperature and the level of particulate emissions from the gasification process. The ash content of a feedstock determines the complexity of a gasification systems filtering system in relation to the end-use application. Handling of high ash feedstocks can also pose a problem due to high abrasion and erosion characteristics.

The ultimate analysis method is a more complex technique used to determine the percent by weight of the individual components of a feedstock. Through the ultimate analysis a better understanding of a feedstock's gasification process can be obtained. The extent of air emissions of nitrates, sulfates, and heavy metals can also be estimated.

Probably the most important property of a feedstock is its heating value. Normally the higher heating value (HHV), is reported from tests using an adiabatic bomb calorimeter.

The lower heating value (LHV) is then calculated by subtracting from the HHV the energy required to vaporize the water in the fuel and the water formed in the combustion process.

Ash composition and fusion temperatures are important considerations in thermochemical conversions of biomass feedstocks. Ash composition indicates the potential for the formation of slag deposits on combustor surfaces and possible disposal problems of the ash. Slag is formed when the temperature rises above the liquid point of the eutectic mixtures in the ash. Slagging and the formation of clinkers can greatly reduce the quantity and the quality of the produced gas affecting the gasifier's overall performance.

Approximations of chemical properties of wheat and barley straw, ponderosa pine and livestock manure are shown in tables 9 through 11, along with traditional fuels for comparison.

Ebeling and Jenkins found that with the exception of ash content, the variations between fields of small grain residues is small. The volatile carbon matter (VCM) and the fixed carbon (FC) varied about 3%, while the ash varied as much as 20%. The ash variability is due to dirt contamination caused by such factors as harvesting method, transportation of residues, weather conditions, soil conditions, and soil type.

Manure, like straw, also shows a wide variation in ash

content between samples. This can be attributed to the amount of dirt contaminating the samples.

Table 9. Chemical analysis of biomass and traditional fuels. Jenkins and Ebeling 1985 and Ebeling and Jenkins 1983.

Chemical Analysis Fuels	HHV	LHV
	(Btu/lb d.b.)	
Biomass		
Barley Straw	7,442	6,982
Wheat Straw	7,528	7,090
Ponderosa Pine	8,608	8,083
Livestock Manure	7,094	-----
Traditional Fuels		
Coal	12,709	-----
Fuel Oil	18.836	-----
Natural Gas	24,103	-----

Table 10. Proximate analysis of biomass and traditional fuels. Jenkins and Ebeling 1985 and Ebeling and Jenkins 1983.

Proximate Analysis Fuels	VCM[1]	ASH	FC[2]
	(% by weight d.b.)		
Biomass			
Barley Straw	68.8	10.3	20.9
Wheat Straw	71.3	8.9	19.8
Ponderosa Pine	82.5	0.3	17.2
Livestock Manure	50.5	41.3	8.2
Traditional Fuels			
Coal	44.4	4.2	51.4
Fuel Oil	-----	1.8	----
Natural Gas	100.0	---	----

[1]. Volatile Carbon Matter
[2]. Fixed Carbon

Table 11. Ultimate analysis of biomass and traditional
        fuels.
        Jenkins and Ebeling 1985 and Ebeling and Jenkins
        1983.
==
Ultimate Analysis

Fuels	C	H	N	S	Cl	ASH	O
				(% by weight d.b.)			

Biomass

Fuels	C	H	N	S	Cl	ASH	O
Barley Straw	39.92	5.27	1.25	----	----	9.75	43.81
Wheat Straw	43.20	5.00	0.61	0.11	0.28	11.40	39.40
Ponderosa Pine	49.30	6.00	0.06	0.01	0.01	0.30	44.36
Livestock Manure	37.40	5.60	2.80	0.05	----	26.30	27.40

Traditional Fuels

Fuels	C	H	N	S	Cl	ASH	O
Coal	71.50	5.30	1.20	0.90	----	4.60	16.90
Fuel Oil	84.67	12.40	----	1.16	----	1.81	-----
Natural Gas	72.00	23.00	----	----	----	----	5.00

Physical Properties

The physical properties of biomass are important factors that can affect its use as a feedstock. Three critical physical properties include:

1. particle size;

2. bulk density; and

3. moisture content.

The particle size directly affects the bulk density of the fuel and also the type of gasifier to be used. The bulk density of the feedstock is dependent not only on the material but also on the harvesting method, moisture content, handling method, and on any densification process that may be used. Moisture content directly affects the available energy in the feedstock. The moisture acts as a heat sink in the fuel and therefore lowers the combustion

efficiency. This results in a lower reactor temperature and there is an increase in tar content of the producer gas. High moisture feedstocks are difficult to store because of the dangers of spontaneous ignition and bacterial build-up.

The following list shows desirable properties for gasifying biomass feedstocks (Sofer and Zaborsky 1981):

1. average moisture content of less than 50%;
2. average heating value (HHV) of not less than 4,214 Btu/lb;
3. average feedstock size range > 0.5 and < 3.0 in.;
4. ash fusion temperature of not less than 2,100 °F;
5. low ash content (6 - 10%);
6. easy ignition characteristics; and
7. uniform chemical composition.

Harvesting and Handling of Biomass Feedstock

The operations of harvesting and handling of biomass feedstocks may be influenced by the type of delivery system, the impact of biomass harvesting on the environment, and the integration of the system into farming practices. The delivery systems generally include collection, transportation, processing, and storage of the feedstock. Many factors influence the design of a delivery system besides the type of gasification system. These factors include (Jenkins and Sumner 1985):

1. physical and chemical properties of the biomass;

2. the season of the biomass production;

3. harvest and terrain conditions;

4. the scale of the biomass conversion system;

5. the types and yields of biomass within the region;

6. the type of conversion technology;

7. economic and financial constraints;

8. political regulations and incentives; and

9. environmental and social impacts.

These factors affect the design and operation of collection and processing equipment, transportation cost, and storage characteristics. Furthermore, the design of the conversion system will in turn be affected by the design of the delivery system (Jenkins et al. 1983).

Biomass feedstocks generally require some method of collection at the region of production. Collection may be as simple as gathering the feedstock and packaging it for transport or it may entail some processing such as baling, cubing, or chipping.

Processing of biomass residues can include drying, grinding, densification, or screening. The reason for processing biomass feedstocks is to meet the fuel specifications of the gasifier by adjusting moisture content, bulk density and/or particle size distribution. Any combination may be required before collection, transportation, storage, or gasification of the feedstock.

The extent of feedstock processing is dependent on the type of conversion and material handling system to optimize the performance and the economics.

The cost of transporting biomass is dependent on the distribution of the source, ease of access, and bulk density. In cases where the feedstock has a low bulk density, a densification process may decrease transportation costs. Often the cost of transportation is the limiting factor in the development of large scale gasification facilities (Jenkins and Sumner 1985). For this reason a careful study on the distribution of the feedstock, the residues package type, and the mode of transportation should be completed for a proposed facility. On a farm scale, the cost of transportation is often less important because the supply is usually close at hand.

Storage is another important factor in the handling of biomass. Biomass feedstocks should be protected from the weather to maintain their quality. Weathering causes a general deterioration of the feedstock, increases the ash content and decreases the energy content. Generally, biomass feedstocks are seasonal and require storage for a facility that operates throughout the year, either continuously or periodically. For both large and small scale conversion systems the amount of required storage can be quite large, therefore, a further densification may be economically justified.

Crop Residues-Primarily Straw

All of Montana's small grain crops are harvested by one of two methods:

1. swathing and then combining; and

2. direct combining.

Costs for both methods of harvesting are tied to primary production costs and not residue collection. The method of swathing and combining, without spreading the straw, leaves the straw residue in an ideal position for collection. The harvesting operation of direct combining processes a smaller portion of the crop. Most of the straw is left standing and it often would require swathing before it could be collected. This additional operation adds to collection costs and may cause the system to become infeasible.

The use of crop residues as a source of biomass lends itself ideally to the use of existing forage harvesting equipment for collection. Several methods of collection could be utilized and include:

1. baling (small or large square and round bales);

2. cubing; and

3. stacks.

Baling of the crop residues can give several package forms. The large square bales and round bales have a higher bulk density than small square bales. Also, the large bales require less labor and energy input to collect and handle in the field and gasification site.

Cubing of the straw gives it the highest bulk density of all the three possible operations. This could be very important in lowering costs if the transportation distance is quite long. Cubing also produces uniformly sized feedstock that can ease handling and reduce bridging during gasification. The problem with cubing is that it is a very energy and labor intensive job and the resulting cubes are of low quality.

The last type of straw collection is stacking. This method has the lowest bulk density of the three and therefore is the most costly to transport. These stacks can be hard to handle and haul long distances.

In Montana a swathing-combining-large bale system would probably be the best choice for the collection of crop residues from a economic and practical standpoint. For on-farm conversion systems the farmer would probably use his own forage harvesting equipment rather than use additional capital to obtain the optimum collection system.

Storage of crop residues can be a problem for a gasification facility. For both large and small scale conversion systems the use of land for storage may be a problem. Jenkins and Knutson (1984) estimated that about 40 acres of land would be required to store a year's supply of big round straw bales to power a 25 MW facility. One solution to on-site storage is field storage but this could be a problem for continuous cropping and irrigation

practices. A further densification process may be profitable
if the cost of the process is less than the cost of saved
storage.

Weathering of the crop residues results in loss of fuel
value. Dobie and Haq (1980) evaluated the storage of
uncovered big round bales of rice straw of varying moisture
contents. Their findings showed that the heating value
declined and the ash content increased with the higher
initial moisture content. As a result, covered storage could
be used to stop weathering but the costs increase. Sumner et
al. (1984) performed storage experiments with wheat straw
and other types of biomass. They found that spraying wheat
straw bales with asphalt, tar, and motor oil did not reduce
water absorption compared to the bales with no covers. The
bales with the polyethylene covers prevented most of the
water buildup from rainfall. Placing the bales on coarse
drained soil reduced moisture transfer from the ground.

Animal Wastes

Animal wastes provide a potential source as a
gasification feedstock in areas where they are available in
large amounts. As mentioned, earlier feedlots and dairy
farms would probably be the best locations for collecting
manure because of the confined areas. This is necessary in
order to concentrate wastes and keep collection costs down.
Dairy barns are an ideal location for collection of dirt-
free wastes for they use paved floors and various manure

collection schemes such as drag chain gutter cleaners or slatted floors. The collected manure can then be stored in a pit or pile for use in a gasifier.

The main problem with the use of manure as a biomass feedstock is the fact that fresh manure contains approximately 88% moisture. The manure must be dried before it can be gasified. The manure may be sun dried but problems in weather variation may interrupt the gasification schedule. Usually the manure is dried using exhaust heat from the gasifier. This process requires a large amount of heat energy which decreases the net energy production of the system. Dried manure can contain different sized particles ranging in size from fines to sizable clods. Manures are gasified in fluidized bed gasifiers because of their high ash content and the clod-sized feedstock may have to be broken up if it has not occurred during handling.

Wood and Wood Wastes

Wood in the form of chips or sawdust is an excellent biomass feedstock. A farmer contemplating using wood for on-farm gasification must decide whether to produce his own feedstock or obtain it from a mill. There are advantages and disadvantages to each source, therefore a combination may be more suitable. Harvesting wood for gasification is a possibility for a site that is located near large timber stands. For small conversion systems a portable wood chipper

can be used to process the wood at the harvesting location. Larger systems may use tub grinders to chip large amounts of wood at the gasification site (Arthur et al. 1982).

Approximately 3.8 lb of green wood are required to produce one kWh of electricity. Therefore, even small scale conversion systems require large amounts of wood. With all the handling of the feedstock, an on-farm handling system should be designed to be reliable, minimize labor requirements and make use of existing equipment. Handling equipment can include chain and belt conveyers, well built augers, and tractor mounted front-end loaders.

Often wood obtained from harvest or sawmills contains a moisture content of 50% by weight. The water is held by the wood in two ways. In green wood, water is held by capillary action between cell walls, giving green wood its characteristically wet feel. The second method for holding water in wood is by weak molecular bonds. This water exists in the cell walls and cannot be seen or felt. Water is held by both methods in wood with a moisture content above 30% (d.b.) while below 30% the water is held by the molecular bonds.

Wood to be used as a feedstock for gasification must have a moisture content below 20% in order to maintain the quality of the produced gas. Drying wood with unheated air can lower the moisture content to 14%, but this is dependent on the species of wood, the air temperature, and the

humidity. The use of heated air can lower the moisture content of the wood even further to approximately 0%. Supplemental heat may have to be added to the drying air during cold days with high humidity. In an actual on-farm situation the feedstock handling system would need a building for both storage and drying of large quantities of wood. A team of researchers at North Carolina State University suggest that a grain bin equipped with fans and a drying floor would make an ideal storage and drying facility.

A dry, well ventilated storage area is not only a necessity from a gasification stand-point but also for health reasons. Wood chips allowed to sit in a damp storage area for an extended period of time can become diseased with fungi and bacteria. Eventually the fungi will develop spores that can cause allergic reactions in humans.

Environmental Problems of Residue Collection

An operator who intends to use redidues should consider that there are environmental disadvantages to removing all the residue from the soil surface. Crop and forest residues, when left on the surface or incorporated into the soil, assist in the prevention of soil erosion by rain and wind, retain moisture by trapping snow and allow for penetration of rainfall, and enrich the soil with organic matter. Rainfall and wind erosion can be a serious problem in Montana. Sudden thunderstorms and gusting winds can remove

large amounts of top soil from barren ground. The effects of
soil loss can have detrimental effects on crop yields and
tree growth for many years. Residues help to trap snow in
the winter and improve soil moisture for spring growth. Crop
residues incorporated into the soil help to prevent the soil
from compacting, allowing for better moisture penetration.
Biomass residue helps to replace nutrients and organic
matter in the soil. The effects of continuous residue
removal on the nutrient and organic matter content of the
soil depends on the type of soil and its reserves.

Matching Gasifiers With Feedstocks

The type of gasifier used in a gasification system is
determined by the type of feedstock used and the end-use
application intended for the produced gas. The properties of
feedstock in part control the method of gasification. Small
grain straw and manure have a very high ash content as
compared to wood (table 10). Therefore, these high ash
feedstocks are best suited for gasifiers able to handle the
high ash content. As shown in chapter 2, fixed-bed updraft
gasifiers and fluidized-bed gasifiers are best suited to
handle these high ash feedstocks. Particle size is also an
important feedstock property that affects the method of
gasification. Fixed-bed gasifiers require feedstocks the
size of wood chips, so manure would be unsuitable for fixed-
bed gasification. Unprocessed straw is stringy and must be

cubed or ground to meet gasification requirements for fixed-bed and fluidized-bed gasifiers respectively.

The end-use application also dictates the type of gasifier to be used in a system. Applications using producer gas to fuel internal combustion engines require low tar content gas. Fixed-bed downdraft and fluidized-bed gasifiers are best suited to produce low tar content gas.

In conclusion, fixed-bed downdraft gasifiers fueled with wood and fluidized-bed gasifiers fueled with manure or ground small grain straw give the best gasifier-to-feedstock matches.

CHAPTER 6

ECONOMIC ANALYSIS

The major factors influencing a farmer's decision to build a gasification system are the economics of this energy source when applied to his specific end-use applications. The system economics are different for each site because of feedstock type and distribution, system size, end-use application, and the biomass collection equipment. The economic analysis of a gasification system is therefore site specific and must include analysis of equipment costs, feedstock costs, and operating costs.

Equipment Costs

Biomass harvesting and handling systems vary from site to site. The type of harvest and handling system is dependent on the size of the conversion system, type of conversion system, feedstock type, and feedstock specifications. The three feedstocks considered in this analysis each require a different harvesting and handling system. A crop residue harvesting and handling system consisting of a tractor with front-end loader, large round baler, a hauling wagon or truck, and a tub grinder is assumed to be the most common or standard crop residue

collection system available to the Montana farmer. A manure handling system would make use of existing collection equipment and require the addition of drying and storage facilities. Wood harvesting and handling systems will need hauling, chipping, drying, and storage equipment. In cases where dry wood residues are purchased from a sawmill or a secondary mill the chipping and drying equipment may be eliminated.

The following scenario demonstrates the methodology for calculating equipment costs for the harvest and handling equipment (Kinzey 1986).

Typical procedure for calculating tractor cost:

A 60 HP diesel tractor with front-end loader operating at an average of 40% of rated power is used by the farmer. The purchase price of the tractor is $15,000 and the annual use is approximately 500 hours.

Annual Cost = (Fixed Cost%) * P/100 + (Annual Use) * Variable Costs

P = Purchase Price of Equipment ($15,000)

Fixed Costs (as a % of purchase cost):

Depreciation = (P-S)/L = (P-0.1P)/10 = 0.09P/yr

Int. on Invest. = (P+S)*i/2 = (P+0.1P)*(0.08)/2 = 0.044P/yr

Taxes = 0.015P/yr

Insurance = 0.0025P/yr

Shelter = 0.01P/yr

S = Salvage Value of Equipment (10%)

L = Depreciation Life of Equipment (10 years)

i = Interest Rate (8%)

Total fixed Costs = (0.09 + 0.044 + 0.015 + 0.0025
                + 0.01)P/yr
           = (0.1615)P/yr
           = \$2,422.50/yr

Variable Costs:

Repair and Maintenance = 0.012P/100 h

Labor = \$10.00/h

Diesel Fuel = (60 hp) * (1 gal/ 8.74 hph)
          * (\$1.00 gal)
          = \$6.87/h

Oil = (0.012 gal/h) * (\$3.50/gal) = \$0.042/h

Total Variable costs = (500 h/yr) * (0.012 / 100 h)
                 * (\$15,000) + (10.00 + 6.86
                 + 0.042)\$/h * (500 h/yr)
                 = \$9,351.00/yr

Total Tractor Costs:

Total Annual Tractor Costs = (\$2,422.50/yr)
                      +(\$9,351.00/yr)
                      = \$11,773.50/yr

Total Hourly Tractor Costs = \$23.55/h

Typical equipment costs for harvesting and handling systems are summarized in table 12.

Table 12. Equipment costs.
===

Machine	Fixed Cost ($/yr)	Variable Cost ($/yr)	Total Cost ($/yr)	Annual Use (h/yr)	Total Cost ($/h)
Tractor (60 hp)	2,422.50	9,351.00	11,773.50	500	23.55
Tractor (120 hp)	4,845.00	13,686.00	18531.00	500	37.06
Round Baler	1,292.00	248.00	1,540.00	100	15.40
Hauling Wagon	127.80	21.60	149.40	100	1.49
Tub Grinder	1,650.00	125.00	1,775.00	200	8.88
Drier[1]	-------	--------	--------	---	----

1. The drier cost varies considerably for each site and is included in the cost of the system.

Biomass Feedstock Costs

In some cases biomass feedstocks are assumed to be free sources of energy. However, there are extra costs associated with the use of biomass feedstocks. These costs include collection, transportation, storage, processing, and opportunity costs and must be evaluated in order to determine the true cost of the feedstock.

Collection costs are the first costs incurred in the use of biomass residues. The collection process includes removing the biomass from its growing environment and packaging or processing it into a transportable form.

Transportation costs are incurred with the movement of the biomass from the field to the storage site and from storage to the gasifier. Transportation costs are a function of the feedstock's bulk density and travel distance. Usually

the bulk density of the feedstock is too low to utilize the available load carrying capacity of the transport vehicle without surpassing their volumetric capacity. A densification process may be economically justified if the hauling distance is quite long. Handling costs are often included in the transportation costs. Handling costs include loading and unloading vehicles, and moving of the feedstock at the gasification site.

Processing costs are the costs incurred to convert the feedstock into material that will meet fuel specifications for the gasifier. Processing can include grinding, cubing, chipping, and/or drying of the feedstock.

Storage costs are site specific, because they depend on the seasonal use of the feedstock and the method of storage. The feedstock should be protected from the weather as much as possible to prevent deterioration and subsequent loss in heating value.

Feedstocks have value for alternative uses, often called opportunity costs. These alternate uses are usually not included in feedstock cost estimates. Alternate feedstock uses can include livestock feed, livestock bedding, fertilizer replacement, and the prevention of soil erosion. In some instances biomass is considered to be a waste product and has to be removed from the site. In these cases a portion of the disposal cost may be recovered through gasification. The amount of opportunity costs

present in the feedstock cost is very site specific and putting a value on the opportunity cost often is based only on the judgment of the system operator.

Crop Residues

In the collection of small grain residue, the costs of production, swathing, and combining are considered to be part of the crop production costs, therefore lowering the overall feedstock cost. A large round baler should have a capacity of 6 to 10 ton/h when baling straw. The exact capacity depends on the size and uniformity of the swath and the roughness of the field. Using a capacity of 8 ton/h and combining the hourly cost of the tractor and baler, the packaging cost is $4.87/ton.

The bale wagon has a 10-ton weight capacity, but due to the low bulk density of the straw only 4 tons of straw are carried per load. The tractor can pull the wagon at a road speed of 15 mph. With a combined tractor-wagon cost of $25.04/h the cost for transportation is represented by the following equation:

$$\text{Transport Cost} = \frac{(X \text{ miles}) * (\$25.04/h)}{(15 \text{ mph}) / (4 \text{ ton})}$$
$$= (0.417 * X)\$/ton$$

X = Round-trip Distance, miles.

The handling costs include loading and unloading the wagon and moving straw at the gasifier site. The bales are handled by a tractor eqipped with a front-end loader. The

tractor can handle only one bale (660 lb) at a time with approximately 10 min. handling time per bale. This translates into a handling cost of $11.90/ton, giving a total transportation and handling cost:

Total Trans. and Handling Cost = $(0.417*X + 11.90)$$/ton

When a fluidized bed gasifier system is used in a facility using straw as a feedstock, the straw should be ground to meet the specifications of the gasifier. Grinding the straw gives the feedstock uniformity and lessens the chances of bed channeling. The easiest way to grind large round bales is in a tub grinder. A tub grinder with a 12 ton/h straw capacity will require approximately a 120 hp tractor for power. The cost of a tractor and grinder is estimated at $3.83/ton.

The calculation of the opportunity cost for crop residues includes many factors relative to the region. Wheat and barley straw, in some situations, are left in the field and at other times are harvested for livestock feed and bedding or for disposal in continuous cropping situations. In areas of light soils, special soil conservation methods are needed. Often crop residue is needed to prevent soil erosion and to build up soil humus. If the straw is removed, replacement fertilizer and erosion damages can be added to fuel costs. The dollar value of straw when left in the field is difficult to determine. Alternate uses of wheat and barley straw, such as livestock bedding and feed, give it a

market value and must be considered when utilizing it for gasification.

Often farmers find it advantageous to remove crop residues from the field to control diseases or regulate the trash cover. Utilizing the straw for gasification in these cases provides a way to recover part of the disposal costs.

The following is a summary of small grain feedstock costs;

Collection = $4.87/ton

Transportation and Handling = (0.417*X +11.90)$/ton

Processing = $3.83/ton

Storage = $0 - ?

Opportunity = $0 - ?

Total Fuel Cost = (0.417*X + 20.60
                  + Storage & Oppor.)$/ton

A total fuel cost of $40.00/ton or $2.66/MBtu (HHV = 7,524 Btu/lb) is probably a maximum cost estimate for straw.

<u>Animal Wastes</u>

As previously discussed, the value of animal wastes as a biomass feedstock depends on its being available in substantial amounts in relatively confined areas. The ideal case would be a dairy farm where the cattle are kept indoors for part of the day. Modern dairy barns are equipped with manure removal systems. These removal systems include self-cleaning gutters or slatted floors and a storage pit or pile. Since the collection of the manure makes use of the

existing disposal system, collection costs are not a factor.

A major cost for manure usage is the drying of the manure. Raw manure is approximately 88% water, therefore to dry the manure in a relatively short time will require the use of heated air. The best way to dry the manure would probably be in a small rotary kiln using heat generated from the gasification system. The manure will have to be dried from 88% moisture content to about 10% requiring:

```
Total Heat Required = (0.78 lb water/lb wet manure) *
                      (2,000 Btu/lb water) *
                      (2,000 lb/ton) * (7.5 tons
                      wet manure/ton 10% m.c.)
                    = 23.4 MBtu/ton 10% m.c. manure
```

Note: Using 2,000 Btu/lb water allows for heat absorbed by the manure and exhausted heat from the drier.

The total heat required to dry the wet manure to a 10% moisture content is calculated to be 23.4 MBtu/ton. If waste heat and the heat provided from the direct combustion of the producer gas were used to dry the wet manure (assuming 100% conversion and collection efficiency), only 17.229 MBtu/ton of heat could be collected. Therefore, waste heat from gasification could only be used to supplement another drying method.

Using natural gas at $0.003/ft^3 for comparison purposes, the cost of the heat required for drying is:

```
Drying Cost = (23,400,000Btu/ton 10% m.c.)
              *($0.003/ft3)/ (885.6 Btu/ft3)
            = $79.27/ton 10% m.c. manure
```

Because of possible collection problems, enough manure should be dried to maintain a two-or three-day fuel supply. The storage area size for dried manure is dependent on the size of the conversion system and the required reserve. Small systems using a short leeway could possibly use the feedstock hopper for storage.

Another important cost is the opportunity cost of using manure as fertilizer. The opportunity cost depends on the local market for manure as fertilizer. The cost can vary from $0.00/ton upwards. In this cost estimate the opportunity cost is assumed to be $5.00/ton of 10% m.c. manure.

The following is a summary of animal waste feedstock costs;

    Collection = $0/ton
    Transportation = $0/ton
    Processing (drying) = $79.27/ton (10% m.c.)
    Storage = $0/ton
    Opportunity = $5.00/ton (10% m.c.)
    Total Animal Waste Cost = $84.27/ton (10% m.c.)

Assuming livestock manure has a heating value of 7,094 Btu/lb d.b., the total cost of $84.27/ton translates into $5.94/MBtu. The total cost for a dry ton of manure is quite large with the majority of the cost being drying costs. A site considering using manure as a possible feedstock source should look at alternative drying methods as it would not be

practical to use natural gas for drying manure. These methods could include solar drying or techniques of draining away excess water.

Wood and Wood Wastes

The cost of wood for biomass feedstock depends on the source of supply. The wood can be purchased from a mill or harvested directly from the forest.

Wood residue that is purchased from a mill can be in the form of chips or sawdust. In the case of a primary mill the chips are green thus requiring drying before gasification. Sawdust produced from cutting dried lumber is suitable for gasification in a fluidized bed without drying. Residues from a secondary mill consist of both small blocks and sawdust in a dried state. Wood residue generally becomes a disposal problem for a mill and the cost of the wood for fuel use is usually the cost of transportation and drying when needed.

The harvesting of logs and forest residues involves the cost of collection, processing, and transportation. The collection of the residues can include falling and bunching, skidding, and/or processing. The collection process can require a lot of labor and equipment usage on difficult terrain. In addition, forest residues are bulky and contain about 50%, moisture which requires chipping and drying, thus increasing the feedstock cost.

Combe (1983) estimated the cost of harvesting logging residues to be $57.00/dry ton while the costs to harvest other forest residues could be as high as $111.00/dry ton of wood in Montana. These costs assume that the harvesting is done by a commercial logging company. The costs may be lower for a farmer to harvest the residue for his own system. If a mill is close by, mill residues would be the best source of supply.

There is a large degree of uncertainty in the cost of wood feedstock and the requirements of each gasification site, so the cost of wood is assumed to range from $0.00 to $80.00/dry ton. Assuming wood has a heating value of 8,608 Btu/lb (d.b.), the cost of wood energy ranges from $0.00 to $4.65/MBtu.

Operating Costs

The operating cost for any piece of equipment includes costs such as those for repair and maintenance, fuel, supplies important to the operation, insurance, and labor. In this case, the operational costs for a gasifier are assumed to include repair and maintenance, supplies, insurance, and labor costs with the exclusion of fuel or feedstock costs. In this economic analysis, the development of feedstock costs is assumed to warrant its own separate analysis. The operating cost for a gasifier is very specific to the type of gasifier system used and the type of feedstock utilized.

The size of a gasification facility and the extent of automation is a factor in considering the magnitude of labor and maintenance costs. Also, one type of gasification technology may require more maintenance than another method. A fluidized-bed gasifier usually requires an extensive filtering system requiring extra monitoring and maintenance. Fixed-bed systems are prone to slag build-up which should be periodically removed to allow for optimum performance of the gasifier. Also, different gasification systems require different start-up and shut- down procedures that vary labor demand.

A general rule of thumb is that operating costs are approximately 5% of the gasification system cost (Curtis et al. 1982). The costs for repair/maintenance and labor, insurance, and supplies are assumed to be 3%, 1%, and 1% respectively of the installed system cost. This analysis divides the operating cost into repair and maintenance (2%), insurance (1%), and supplies (1%), totaling 4% of the installed cost of the system. Labor costs are treated separate from maintenance costs due to the possibility of large variations of system use per year from one system to another. Each gasification system is assumed to require 2 man hours per 10-hour day and at a hourly rate of $10.00/h.

Gasification System Models

In this section, four site specific scenarios with

different end-use applications are modeled. The four
models cover the possible agricultural end-use
applications mentioned in chapter 4:

1. irrigation pumping;

2. grain drying;

3. heating of livestock buildings; and

4. cogeneration.

The method used for assessing the economics of each
model is described by the following steps:

1. Each hypothetical system is sized according to the
   scenario requirements.

2. The amount of needed feedstock energy is determined.

3. The installed cost of the system is estimated.

4. The yearly fuel displacement credit is calculated
   using the least expensive conventional energy
   alternative.

5. Operation costs that include; labor, insurance, and
   repair and maintenance costs are calculated.

6. The required calculated system parameters are then
   entered into an economic spreadsheet program
   (appendix C). The economic spreadsheet program is
   used to evaluate the economic performance of the
   modeled system.

7. The economic feasibility of the base case is then
   analyzed and a sensitivity analysis is performed on
   assumed parameters. The assumed parameters that are

varied include: interest rates, feedstock costs, estimated fuel displacement, and electricity buy-back rates if electricity is produced.

Model 1. Irrigation Pumping

The following hypothetical scenario is used to demonstrate the sizing and economics of an irrigation/gasification system.

A farmer irrigates 640 acres of wheat against a total head of 160 ft over approximately 1,000 h. The efficiency of the pump is assumed to be 80%. Wheat has a peak water requirement of 0.28 in./day. The required engine pto (power take off) power to drive the pump or pumps is:

Engine pto = (0.28 in./day) / (10 h/day) / (3,600 s/h)
            * (640 acres) * (43,500 ft^2/acre)
            / (12 in./ft) * (62.4 lb/ft^3) * (160 ft)
            / (80%/100) / (550 ft lb/sec/hp)
          = 409 hp

The producer gas fueled engine and gasifier are assumed to have conversion efficiencies of 20% and 65%, respectively. The energy requirements are:

Engine fuel energy = (409 hp) * (2545.2 Btu/h/hp)
                     / (20%/100)
                   = 5,204,934 Btu/h
                   = 5.2 MBtu/h

Feedstock energy = (5.2 MBtu/h) / (65%/100)
                 = 8.0 MBtu/h

The possible feedstock types for the irrigation/gasification model use include straw, wood and wood wastes, and manure. A fixed-bed downdraft gasifier fueled with wood chips and a fluidized-bed gasifier using any of the three

fuels could be used at this site. The approximate installed costs for the fixed-bed downdraft and fluidized-bed gasifiers are $100,000 and $140,000 respectively (Sure-Lite Manufacturing). The estimated installed cost includes the feeding system, gasifier, cleaning and cooling system, irrigation motor, and miscellaneous (housing, controls, etc.).

Using electricity as the least expensive alternative energy for irrigation pumping at a cost of $0.031/kWh with a electrical motor efficiency of 90%, the estimated fuel displacement is:

```
Est. Fuel Displ. = (409 hp) * (0.746 kW/hp) / (90%/100)
                 * (1000 h/yr) * ($0.031/kWh)
                 = $10,509/yr
```

A reasonable estimate of repair and maintenance, insurance, supplies, and labor costs installed costs are calculated:

```
Repair and Maint. Costs = ($100,000) * (2%/100)
                        = $2,000

Insurance Costs = ($100,000) * (1%/100)
                = $1,000

Supply Costs = ($100,000) * (1%/100)
             = $1,000

Labor Costs = (1,000 h/yr) * ($20/10 h/day)
            = $2,000/yr
```

A base case is developed to establish a benchmark to determine whether a gasification system would be economically feasible. The base case represents realistic economic system parameters and assumptions such as taxes and

other fixed costs.

Base case assumptions:

1.	System Cost (Downdraft)	$100,000
2.	Initial Investment	20%
3.	Loan Interest Rate	8%
4.	Loan Payback Period	10 yr
5.	Period of Operation (10 h/day, 5 day/wk. 20 wk/yr)	1,000 h
6.	System Life	10 yr
7.	Tax Rate: Federal State	30% 7%
8.	Feedstock Cost	$2.00/MBtu
9.	Fuel Displacement Credit	$10,509/yr
10.	Discount Rate	12%

Figure 22 shows the output of the economic spreadsheet program displaying the net present value versus years for the base case. The zero net present value line represents the break-even line. The output shows a steady decline after the first year of operation. The discontinuity of the first year is due to the effect of the investment tax credit.

Figures 23 through 25 show present net value versus years for variations in interest rates, feedstock costs, and estimated fuel displacement credit respectively. The base case interest rate of 8% was varied from 4% to 12% to study its effect on the analysis. The feedstock cost was varied from $0/MBtu to $5/MBtu and the fuel displacement credit was varied from 0 to 4 times the estimate.
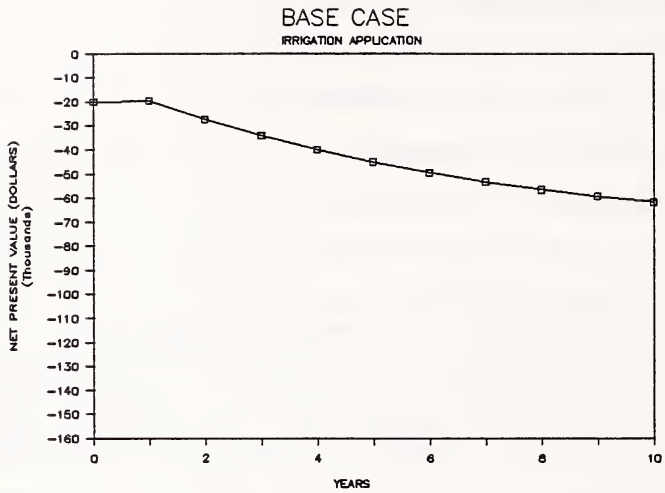
Figure 22. Base case - irrigation model.
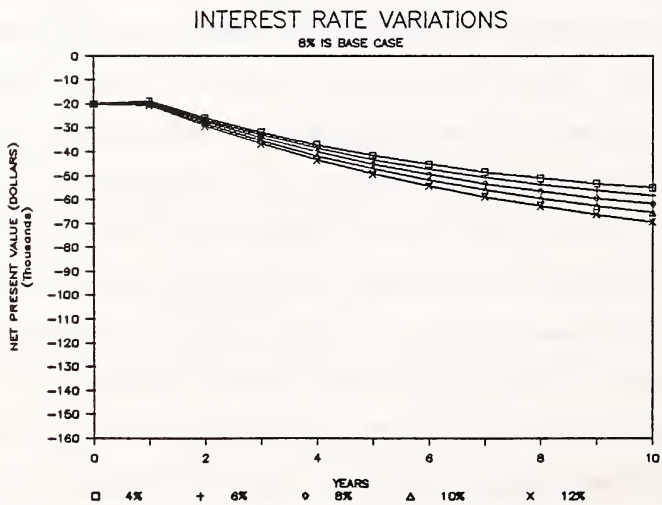
Figure 23. Interest rate variations - irrigation model.
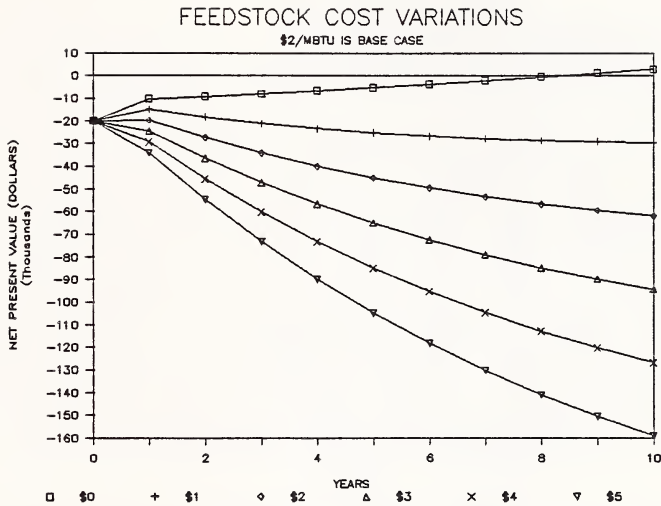
Figure 24. Feedstock cost variations - irrigation model.
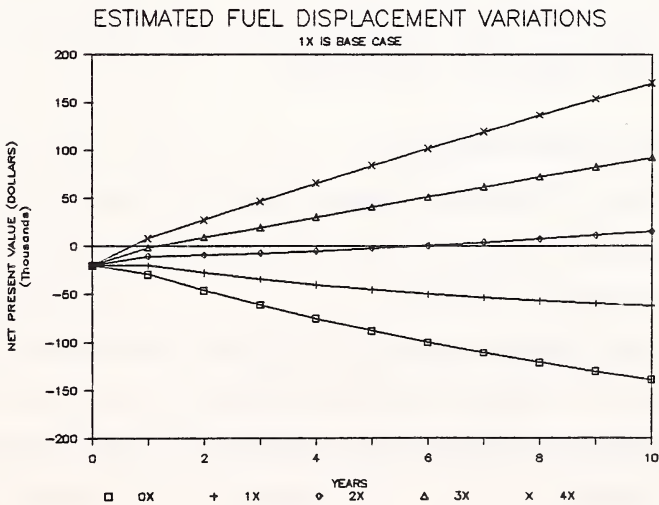
Figure 25. Estimated fuel displacement variations - irrigation model.

The base case graph and the sensitivity graphs show that at this hypothetical site the gasification system used to pump irrigation water is uneconomical. Ideal situations with zero feedstock cost and conventional fuel costs at 2 times the present cost of electricity proved to be economical. The site was considered uneconomical because situations with zero fuel cost and high conventional fuel prices are deemed unrealistic at the present time. Therefore, the main reasons for this site's economic failure is due to the high installed cost and low annual use.

The use of the lower cost fixed-bed downdraft gasification proved uneconomical, therefore the higher cost fluidized-bed system is also assumed to be uneconomical. To increase the usage of the system, the designer may consider multiple tasks for the system.

Model 2. Grain Drying

The following hypothetical scenario is used to demonstrate the sizing and economics of a grain drying /gasification system.

The farmer wishes to dry the wheat harvested from 640 acres of irrigated wheat yielding 45 bu/acre. The grain is harvested at 18% moisture content and is to be dried to 13% for storage.

Total Heat Required = (45 bu wheat/acre) * (640 acre) *
                      (60 lb/bu wheat)
                      * (0.0575 lb water/lb wheat)
                      * (2,000 Btu/lb water)
                    = 198,720,000 Btu = 198.72 MBtu

Note: Using 2,000 Btu/lb water allows for heat absorbed by the wheat and not used in evaporating water and also the heat remaining in the air that is exhausted from the drier.

Assuming that the drier can dry 2,000 bushel batches, in a 10 h/day drying cycle, a total of 144 h or 15 days are needed. The gasifier is assumed to have a thermal efficiency of 80% when used in a direct combustion process. The gasifier size and feedstock energy required is:

Gasifier Size = (198.72 MBtu) / (144 h)
              = 1.38 MBtu/h

Feedstock Energy = (1.38 MBtu/h) / (80%/100)
                 = 1.725 MBtu/h

The approximate installed cost for the fixed-bed downdraft and fluidized bed gasifiers to supply heat for the drier are $60,000 and $100,000 respectively (Sure-Lite Manufacturing). Using natural gas as the least expensive alternative energy for drying grain at a cost of $0.003/ft^3 and burning efficiency of 80%, the estimated fuel displacement is:

Est. Fuel Displ.= (198.72 MBtu/yr) / (80%/100) /
                  (885.6 Btu/ft^3) * ($0.003 ft^3)
                = $841/yr

A reasonable estimate of operational supplies, repair and maintenance, and insurance is:

Operational Supplies = ($60,000) * (1%/100)
                     = $600

Repair and Maintenance = ($60,000) * (2%/100)
                       = $1,200

Insurance Cost = ($60,000) * (1%/100)
               = $600

Base case assumptions:

1.	System Cost (downdraft)	$60,000
2.	Initial Investment	20%
3.	Loan Interest Rate	8%
4.	Loan Payback Period	10 yr
5.	Period of Operation (10 h/day, 5 day/wk, 3 wk/yr)	144 h
6.	System Life	10 yr
7.	Tax Rate: Federal State	30% 7%
8.	Feedstock Cost	$2.00/MBtu
9.	Fuel Displacement Credit	$841
10.	Discount Rate	12%

Figure 25 showsthe output from the economic spreadsheet program using the above base case input parameters. The results are similar to those of the first model except for a lower debt after ten years.

Figures 27 through 29 show present net value versus years for variations in interest rates and feedstock costs respectively. The base case interest rate of 8% was varied from 4% to 12%, the feedstock cost from $0/MBtu to $5/MBtu and the estimated fuel displacement credit from 0 to 4 times the base case.
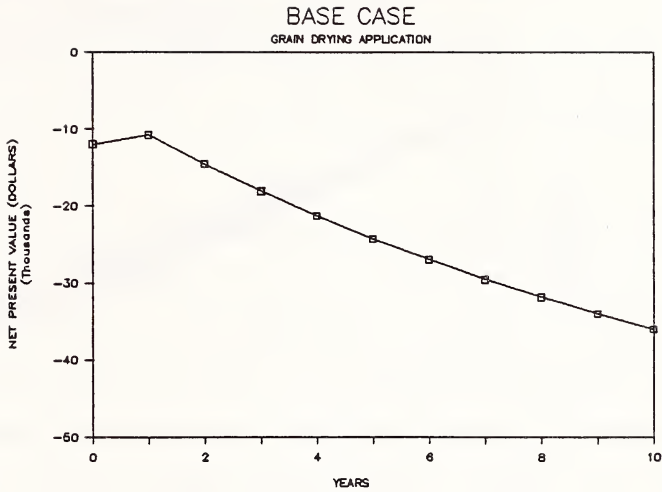
Figure 26. Base case - grain-drying model.
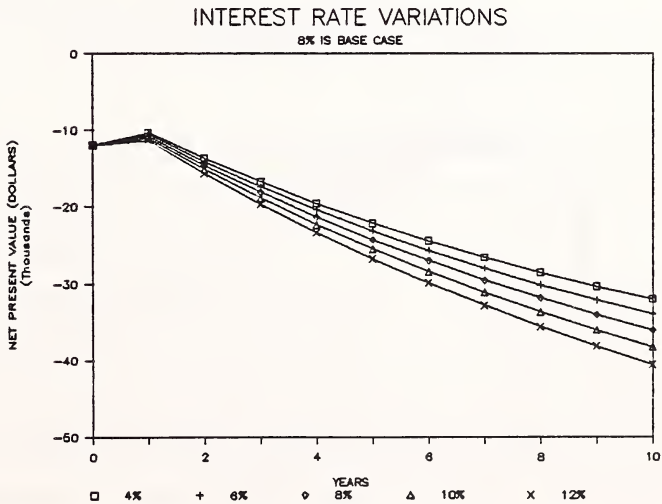
Figure 27. Interest rate variations - grain-drying model.
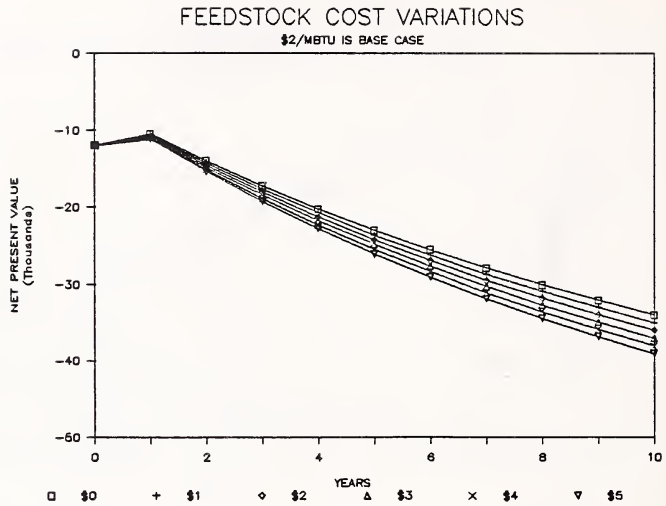
Figure 28. Feedstock cost variations - grain-drying model.
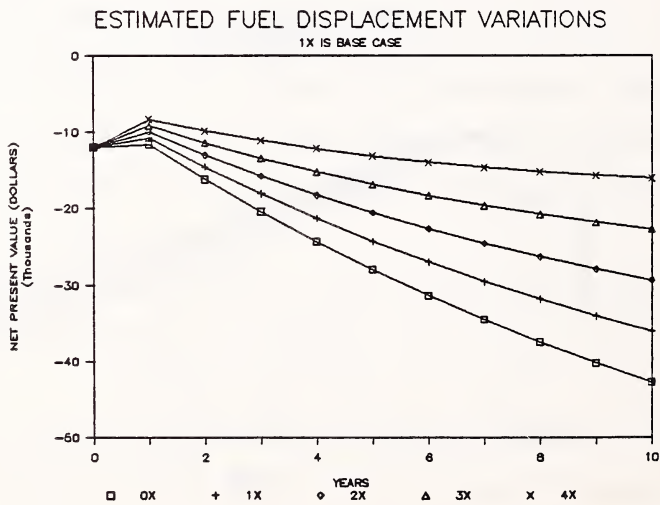
Figure 29. Estimated fuel displacement variations - grain-drying model.

The base case graph and sensitivity graphs show that the gasification system used to provide heat for drying grain is uneconomical. Again the reason for economic failure is due to the high initial cost, low annual use, and low conventional fuel costs.

Ideally, to increase annual system use the gasifier could be used to pump irrigation water and dry the grain for the same 640 acres of land. But as shown in models 1 and 2 the required gasifier size for irrigating pumping and grain drying is quite different. Irrigation pumping required 5.2 MBtu/h of gas energy, while grain drying required 1.38 MBtu/h of heat energy. To size the gasifier to operate both systems would require a compromise of efficiency or size.

Model 3. Heating Livestock Buildings

The following hypothetical scenario is used to demonstrate the sizing and economics of a livestock heating/gasification system. A dairy operation scenario is used because it has a good potential for using the generated heat.

The system design parameters are for a hypothetical dairy operation and are taken from the "Midwest Plan Service Structures and Environment Handbook" 1980. A hypothetical dairy operation is used rather than an actual case because each design is site specific and the data from the Midwest Plan Service describes a more typical operation.

A dairy farmer is considering using a gasification system to help supplement the heating requirements of his operation. The system design parameters used in the scenario are as follows:

Typical herd size:

Milking cows	100
Dry cows	22
Heifer (10 mon. to freshening)	53
Calves (1.5 to 10 mon.)	29
Calves (up to 1.5 mon.)	18

Total animals in herd	222

Space heating:

Milking parlor	70,000 Btu/h
Milkhouse	10,000 Btu/h
Calf housing (1,000 Btu/hr/calf)	18,000 Btu/h

	98,000 Btu/h

Water heating (cleaning):

Bulktank[1] (55 gal/day)	52,000 Btu/day
Pipelines[1] (50 gal/milking)	47,668 Btu/milking
Miscellaneous[1] (30 gal/day)	28,600 Btu/day
Parlor[1] (55 gal/milking)	52,434 Btu/milking
Milkhouse floor[1] (20 gal/day)	19,067 Btu/day
Cow prep.[2] (2 gal/cow/milking)	107,770 Btu/milking

[1.] Water temperature of 165°F.
[2.] Water temperature of 115°F.

Note: The water inlet temperature is assumed to be 50°F.

The farmer plans to milk twice daily and meet all the space and water heating requirements with the gasification system. Since the gasifier will only operate for 10 h/day a heat storage tank will be incorporated into the heating system. The storage system will be designed to meet the following heat usage schedule during the winter.

Table 13. Heat load schedule.

Hour	Gasifier On/Off	Heating Load (Btu)	
		Space	Water
1	on	98,000	0
2	on	98,000	0
3	on	98,000	0
4	on	98,000	Cow Prep. 107,770
5	on	98,000	Cow Prep. 107,770
6	on	98,000	Cleaning 119,168
7	on	98,000	0
8	on	98,000	0
9	on	98,000	0
10	on	98,000	Cleaning 71,067
11	off	98,000	0
12	off	98,000	0
13	off	98,000	0
14	off	98,000	0
15	off	98,000	Cow prep. 107,770
16	off	98,000	Cow prep. 107,770
17	off	98,000	Cleaning 119,168
18	off	98,000	0
19	off	98,000	0
20	off	98,000	0
21	off	98,000	0
22	off	98,000	0
23	off	98,000	0
24	off	98,000	0
Total		2,352,000	740.483

Water is an ideal material in which to transport and store usable heat. Heat energy can be added and removed from a water medium without an energy loss between the transport fluid and the water. The energy balance on a nonstratified storage tank is (Duffie and Beckman 1980):

$$(mC_p)_s dT_s/dt = Q_u - L - (UA)_s(T_s - T_a)$$

m = mass of water in storage.
C_p = specific heat of water.
T_s = temperature of the water in storage.
T_a = temperature of the ambient air.
t = time.
Q_u = energy supply.
L = energy load.
$(UA)_s$ = loss coefficient-area product of the tank.

With the above equation rewritten in finite difference form, the heat energy supply from the gasifier can be solved for by maintaining the appropriate water temperature and heating schedule.

$$Q_u = L + (UA)_s(T_s - T_a) + (mC_p)_s/t(T_{sn} - T_{so})$$

T_{sn} = new temperature of water in storage.
T_{so} = old temperature of water in storage.
m = 10,000 lb
C_p = 1 Btu/lb/^oF
T_a = 40^oF
t = 1 h
$(UA)_s$ = 68.74 Btu/h/^oF

Using the above assumptions and the heating schedule, a gasifier producing approximately 400,000 Btu/h will meet the winter heating requirements. The system will only have to heat water during the summer months or 35% of the year.

A heating load of 400,000 Btu/h is below the minimum capacity of fluidized-bed gasifiers, therefore a fixed-bed system will have be used. Of the available feedstocks,

woodchips are best suited for gasification in a fixed-bed downdraft gasifier.

The direct combustion of producer gas is assumed to have a thermal efficiency of 80%.

Feedstock Energy = (400,000 Btu/h) / (80%/100)
= 500,000 Btu/h

The purchase price of the gasification system is assumed to be $40,000 (Boyette and McKusick 1983). This includes feedstock feeding, solid waste removal, gas filtering, and producer gas burning equipment. Using natural gas as the least expensive conventional fuel alternative ($0.003/ft^3) the estimated fuel displacement is:

Est. Fuel Displ. = (((3,500 h/yr) / (10 h/day) *
(65%/100) * (3,092,483 Btu/day)) +
((3,500 h/yr) / (10 h/day) *
(35%/100) * (740,483 Btu/day))) /
(885.6 Btu/ft^3) * ($0.003/ft^3)
= $2,691

The estimated supply costs, repair and maintenance, insurance, and labor costs are:

Supply Costs = ($40,000) * (1%/100)
= $400

Repair and Maintenance = ($40,000) * (2%/100)
= $800

Insurance Cost = ($40,000) * (1%/100)
= $400

Labor Cost =($10/h) * (2 h/10h-day) * (3,500 h/yr)
= $7,000/yr

Base case assumptions:

1. System Cost (downdraft) $40,000

2. Initial Investment   20%

3. Loan Interest Rate	8%
4. Loan Payback Period	10 yr
5. Period of Operation (10 h/day, 7 day/wk, 50 wk/yr)	3,500 h
6. System Life	10 yr
7. Tax Rate: Federal State	30% 7%
8. Feedstock Cost	$2.00/Btu
9. Fuel Displacement Credit	$2,691
10. Discount Rate	12%

The results for the base case assumptions are shown in figure 30. The graphical output shows a steady decline in the net present value of the system over the ten years. A sensitivity analysis was performed for the assumptions made on current interest rates, feedstock costs, and fuel displacement credit. The results of the sensitivity analysis are displayed in figures 31 through 33.

Even with low interest rates and feedstock costs the system still proved to be uneconomical. Variations of the estimated fuel displacement (figure 33) show the system will break even after 4 years if the current price of natural gas ($0.003 ft^3) quadruples.

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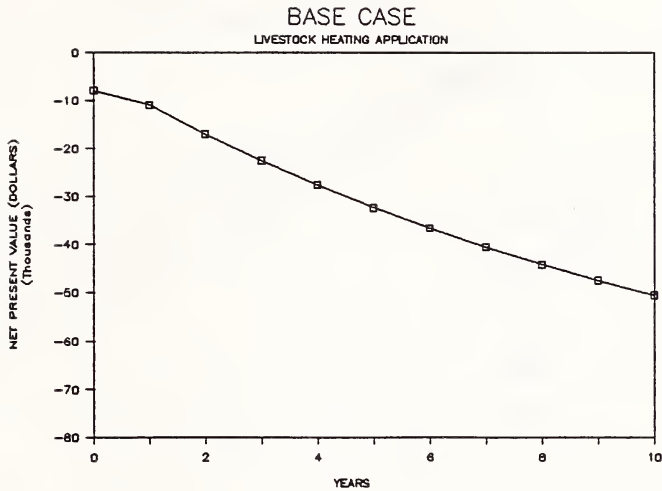
Figure 30. Base case - heating livestock buildings model.
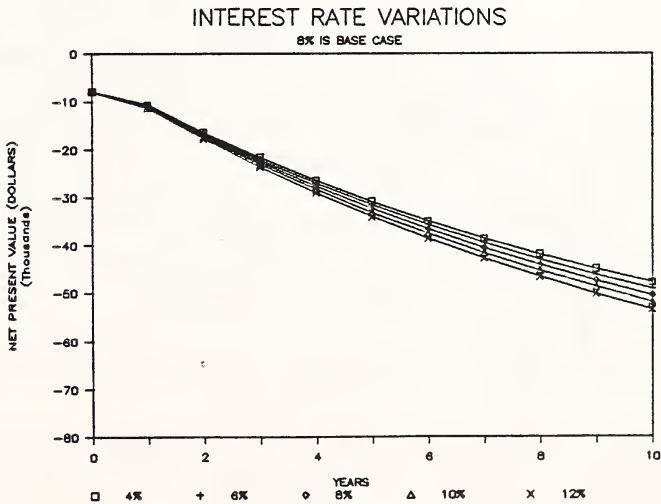
Figure 31. Interest rate variations - heating livestock
buildings model.
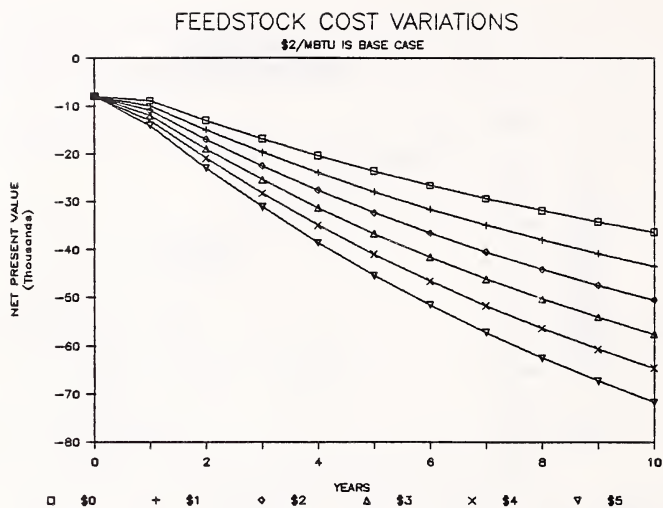
Figure 32. Feedstock cost variations - heating livestock buildings model.
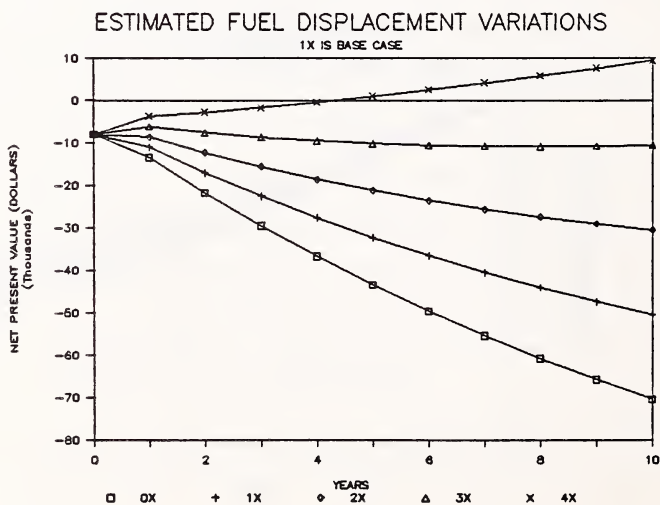
Figure 33. Estimated fuel displacement variations - heating livestock buildings model.

Model 4. Cogeneration

The following hypothetical scenario is used to demonstrate the general sizing and economics for an on-farm cogeneration system.

The farmer is considering using cogeneration to satisfy both heating (400,000 Btu/h) and electrical requirements of the dairy operation. The electrical energy will be produced by an engine/generator set and the heat energy supplied by waste heat. Sizing a system can depend either on the heating load or the electrical requirements of the site. If electrical generation is the primary criteria for the system, sizing is dependent on the electrical needs. The same is true for heating requirements. Often at cogeneration sites the generation of electricity is the primary requirement due to isolation of the site or from prospects of selling electricity to the local utility.

Assuming a 75 kWh electrical load, a 95% generator, 20% engine and 65% gasifier efficiencies, the calculated gasifier size and feedstock energy required are:

```
System Size = (75 kWh/h) / (95%/100) / (20%/100)
              * (3,413 Btu/kWh)
            = 1,347,000 Btu/h = 1.347 MBtu/h

Feedstock Energy = (1.347 MBtu/h) / (65%/100)
                 = 2.072 MBtu/h
```

Approximately 40% of the feedstock energy can be recovered (Boyette and McKusick 1986), resulting in a possible recovery of 829,000 Btu/h of heat. Only 400,000 Btu/h is needed to meet the present winter heating load.

The approximate installed cost for an appropriate fixed-bed downdraft gasifier and fluidized-bed gasifier systems are $60,000 and $100,000 respectively. Using natural gas as the least expensive conventional alternative energy the estimated fuel displacement credit is $2,691 (model 3).

The estimated supply costs, repair and maintenance, insurance, and labor costs for the less expensive fixed-bed downdraft system are:

Supply Costs = ($60,000) * (1%/100)
                      = $600

Repair and maintenance = ($60,000) * (2%/100)
                                 = $1,200

Insurance = ($60,000) * (1%/100)
                = $600

Labor = ($10/h) * (2 h/10 h-day) * ($3,500 h/yr)
          = $7,000

Base case assumptions:

1. System Cost (downdraft)	$60,000
2. Initial Investment	20%
3. Loan Interest Rate	8%
4. Loan Payback Period	10 yr
5. Period of Operation (10 h/day, 7 day/wk, 50 wk/yr)	3,500 h
6. System Life	10 yr
7. Tax Rate: Federal State	30% 7%
8. Feedstock Cost	$2.00/MBtu
9. Fuel Displacement Credit	$2,691

10. Generation Capacity	75 kWh
11. Electrical Rate	$0.013/kWh
12. Discount Rate	12%

The results for the base case assumptions again show the hypothetical model to be uneconomical (figure 4). The graphical output shows a steady decline in the net present value over the life of the system. The 10% investment tax credit shows little effect in countering the high system costs.
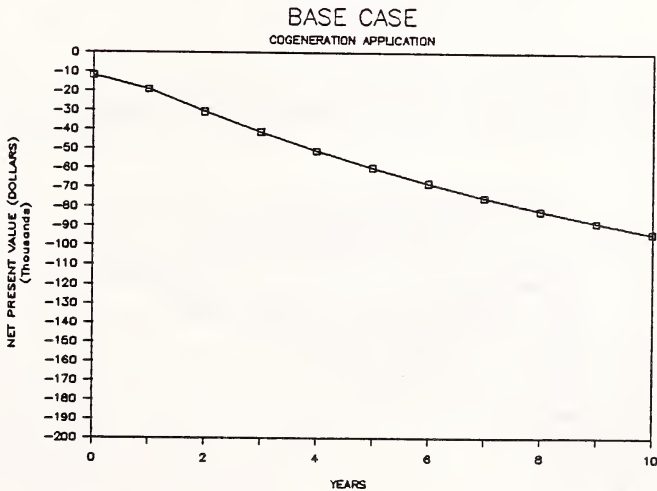
Figure 34. Base case - cogeneration model.

Figures 35 through 38 display the sensitivity of various base case assumptions for this model. The assumptions varied include interest rates, feedstock cost, estimated fuel displacement, and electricity rates.
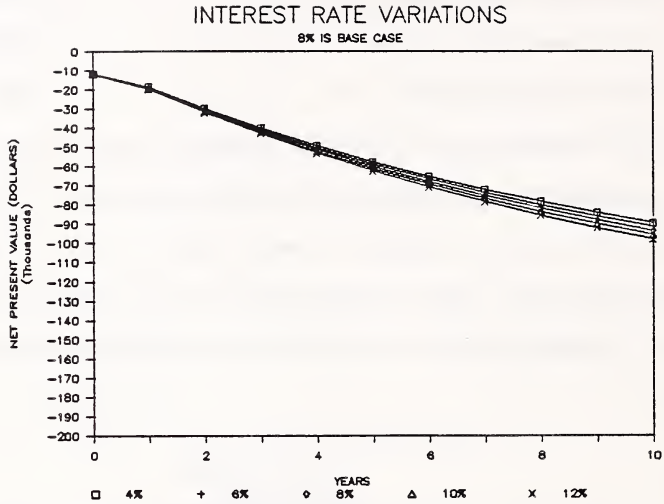
Figure 35. Interest rate variations - cogeneration model.
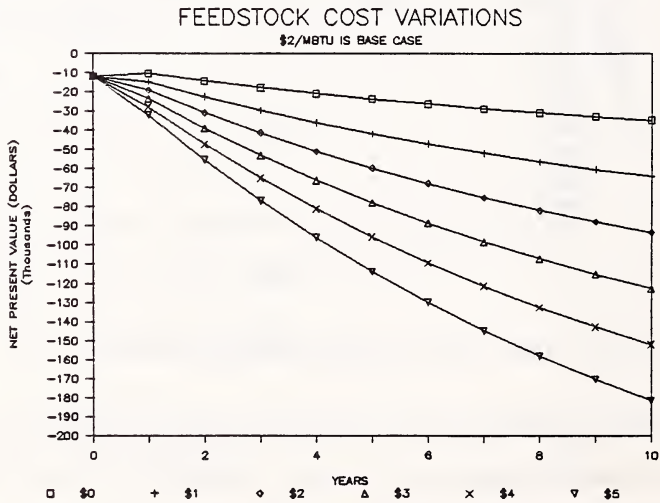
Figure 36. Feedstock cost variations - cogeneration model.

ESTIMATED FUEL DISPLACEMENT VARIATIONS
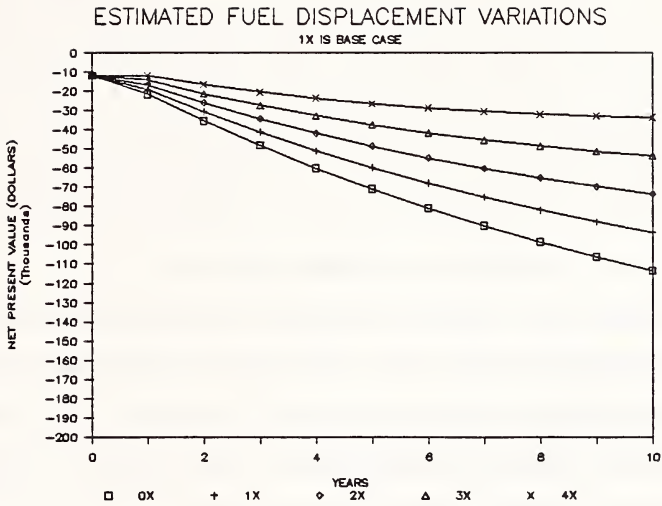
Figure 37. Estimated fuel displacement variations - cogeneration model.

ELECTRICAL PAYBACK RATE VARIATIONS
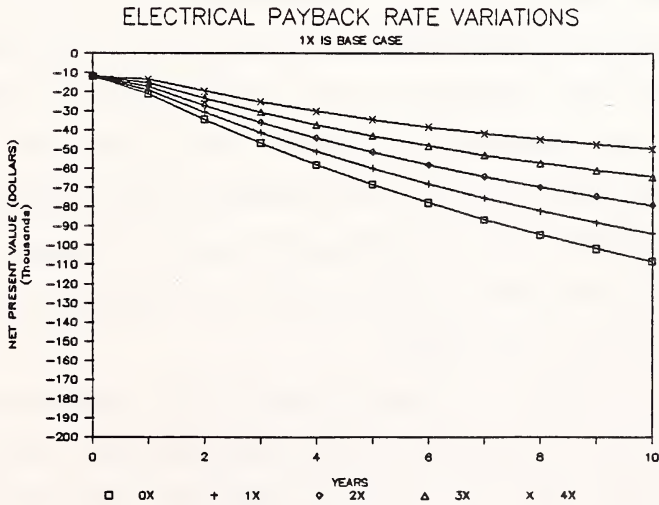
Figure 38. Electricity payback rate variations - cogeneration model.

The base case and sensitivity plots show that this model of an on-farm cogeneration system is uneconomical. Possible parameters causing the economic failure of this model include high feedstock costs, high labor costs, low conventional energy costs and low electrical payback rates.

Summary of Model Results

An economic analysis was performed on each model's base case assumptions using the spreadsheet program. The assumed base case values were an attempt to reflect realistic values for today's economic parameters. The results of all four hypothetical models showed the systems to be economically infeasible for their respective base case assumptions.

The base case assumptions for each model were varied to allow for future realistic assumptions or for errors made in the original assumptions. The sensitivity analyses varied interest rates, feedstock costs, estimated fuel displacement credits, and electricity payback rates. The most sensitive parameters were found to be feedstock costs, estimated fuel displacement, and electricity payback rates. Varying interest rates showed little effect in changing the economic feasibility of the models.

The analysis largest sensitivity was displayed by varying the estimated fuel displacement credit. The irrigation and heating of livestock buildings models actually became feasible when the price of electricity and natural gas was varied to two and four times the current

prices respectively. The irrigation model also became economically feasible when the base case feedstock cost of $2/MBtu was lowered to $0/MBtu. These variations of the base case with zero feedstock costs and double the current convention fuel prices are not realistic in today's economy; therefore, they are considered to be noneconomical. Ideal situations with zero feedstock costs, low interest rates, and high conventional fuel costs generally proved to be uneconomical. In conclusion, the main reason for the model's economic failures are due to the high installed cost of the system.

CHAPTER 7

CONCLUSION

Montana has large amounts of biomass feedstocks that have the potential to alleviate the agricultural industry's dependency on fossil fuels. These biomass feedstocks include small grain crop residues, animal wastes, wood, and wood wastes. Crop and wood residues are the most abundant forms of biomass in Montana. Animal wastes are also a possible gasification feedstock but only in areas where livestock are concentrated.

The amount of feedstock available. the type of materials handling system needed, the type and size of gasifier, and the end-use applications for the energy were found to be very site dependent. The site's energy requirements, feedstock type, and end-use application are the major factors determining the type of gasification system needed. When an application requires a high quality, low tar content producer gas, such as fuel for an internal combustion engine, a downdraft gasifier or a fluidized-bed gasifier with an improved filtering system should be used. Feedstocks such as straw, manure, and sawdust are best suited for a fluidized-bed gasifier because of their high

ash content and small particle size. Wood chips are best suited for gasification in a downdraft fixed-bed gasifier.

The most beneficial energy conversion process for farm use is a combination of heating applications and fuel production for internal combustion engines. The energy produced by these methods can be used to heat livestock buildings, dry grain, generate electricity, and pump irrigation water. System designers should seriously consider cogeneration applications because of their high energy conversion efficiencies. In addition, the gasification feeding system should be a continuous feeding type, for convenience, reliability, and cost effectiveness.

Literature review concerning biomass gasification systems and the four system economic models studied for Montana conditions indicate that on-farm biomass gasification will not be profitable in Montana. There are several major factors that influence this profitability. Biomass feedstocks are often viewed as a renewable and free source of energy; however this study has shown that the cost to convert biomass into usable forms of energy through gasification is quite high. The large investment for an installed system and the low cost for competing conventional fuels makes it difficult to find an economic combination. In addition, the high cost of collecting, transporting, and processing the feedstocks in Montana helps to make gasification systems economically infeasible under current

economic conditions. The successful implementation of biomass gasification on Montana farms will require further design and development to produce a basic low cost biomass gasification package that is capable of gasifying a wide range of feedstocks and is designed specifically for on-farm operation. Small gasification systems suitable for on-farm applications are still mainly in the development and testing stages, making the implementation of gasification systems on Montana farms risky. More research needs to be done on the gasification characteristics of agricultural feedstocks and especially small grain straw to enable Montana farmers to use this large renewable energy source.

A presentation on this study to Montana farmers and ranchers would probably result in poor attendance and little interest due to the unfavorable economics that exist under today's conditions. A proposal has been made to present the information in the form of an ASAE paper to a technical audience. The paper has been proposed for the Pacific Northwest Region ASAE/CSAE annual meeting, to be held September 23-25, 1987 at Lethbridge, Alberta, Canada.

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APPENDICES

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Appendix A

Small Grain Inventory

WINTER WHEAT -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	Acres Planted	Acres Harvested	Yield Per Acre	Production (Bushels)	Acres Harvested	Yield Per Acre (Bu.)	Acres Harvested	Yield Per Acre (Bu.)
					IRRIGATED		**NOT IRRIGATED**	
Flathead........	6,600	6,400	38.8	248,400	1,300	62.0	5,100	32.9
Lake............	6,900	6,500	29.6	192,700	1,000	58.0	5,500	24.5
Mineral.........	100	100	24.0	2,400	0	0	100	24.0
Missoula........	600	500	39.6	19,800	300	50.0	200	24.0
Powell..........	200	200	23.0	4,600	0	0	200	23.0
Ravalli.........	1,100	1,100	29.4	32,300	200	58.0	900	23.0
Sanders.........	1,900	1,500	27.1	40,700	0	0	1,500	27.1
N. WEST	17,400	16,300	33.2	540,900	2,800	59.0	13,500	27.8
Blaine..........	117,500	110,800	27.0	2,991,100	0	0	110,800	27.0
Chouteau........	336,800	322,600	34.8	11,219,300	200	60.0	322,400	34.8
Glacier.........	13,500	11,500	22.5	258,800	0	0	11,500	22.5
Hill............	267,800	254,300	24.7	6,289,000	0	0	254,300	24.7
Liberty.........	103,600	96,500	18.7	1,806,600	0	0	96,500	18.7
Phillips........	58,100	53,600	20.5	1,100,200	200	57.0	53,400	20.4
Pondera.........	120,000	109,700	28.3	3,102,600	2,500	58.0	107,200	27.6
Teton...........	141,400	133,300	31.6	4,212,000	2,800	60.0	130,500	31.0
Toole...........	92,300	86,200	23.7	2,038,800	0	0	86,200	23.7
N. CENTRAL	1,251,000	1,178,500	28.0	33,018,400	5,700	59.0	1,172,800	27.9
Daniels.........	1,500	1,300	10.8	14,000	0	0	1,300	10.8
Dawson..........	78,700	69,200	22.1	1,530,300	0	0	69,200	22.1
Garfield........	49,200	43,200	13.2	568,100	0	0	43,200	13.2
McCone..........	93,200	81,600	22.1	1,802,700	0	0	81,600	22.1
Richland........	67,200	52,800	22.7	1,198,000	0	0	52,800	22.7
Roosevelt.......	27,100	24,600	19.8	486,800	100	34.0	24,500	19.7
Sheridan........	6,400	5,200	21.7	112,700	0	0	5,200	21.7
Valley..........	35,200	30,500	17.4	531,800	100	36.0	30,400	17.4
N. EAST	358,500	308,400	20.2	6,244,400	200	35.0	308,200	20.2
Broadwater......	29,100	24,500	28.1	687,300	400	52.0	24,100	27.7
Cascade.........	126,700	119,800	33.1	3,964,800	500	39.0	119,300	33.1
Fergus..........	124,400	118,100	29.5	3,479,300	0	0	118,100	29.5
Golden Valley...	37,500	34,800	20.3	706,100	400	45.0	34,400	20.0
Judith Basin....	61,000	57,800	29.1	1,683,200	0	0	57,800	29.1
Lewis & Clark...	14,900	14,200	28.7	407,400	200	46.0	14,000	28.4
Meagher.........	11,100	10,700	24.5	262,100	0	0	10,700	24.5
Musselshell.....	33,900	27,000	18.1	487,700	0	0	27,000	18.1
Petroleum.......	8,800	7,800	16.7	130,500	0	0	7,800	16.7
Wheatland.......	32,900	30,500	19.5	596,000	0	0	30,500	19.5
CENTRAL	480,300	445,200	27.9	12,404,400	1,500	45.0	443,700	27.8
Beaverhead......	4,300	3,900	34.2	133,500	100	66.0	3,800	33.4
Gallatin........	31,000	27,600	42.1	1,162,600	3,200	65.0	24,400	39.1
Jefferson.......	5,500	4,800	29.7	142,700	0	0	4,800	29.7
Madison.........	5,600	5,000	28.8	144,100	100	64.0	4,900	28.1
S. WEST	46,400	41,300	38.3	1,582,900	3,400	65.0	37,900	35.9
Big Horn........	105,800	97,400	27.9	2,721,400	800	46.0	96,600	27.8
Carbon..........	14,000	13,000	29.6	384,700	1,500	51.0	11,500	26.8
Park............	12,800	11,700	26.5	310,600	300	53.0	11,400	25.9
Stillwater......	59,100	56,000	22.9	1,284,200	0	0	56,000	22.9
Sweet Grass.....	6,800	6,400	21.9	140,100	100	46.0	6,300	21.5
Treasure........	4,200	4,100	29.0	118,700	300	60.0	3,800	25.5
Yellowstone.....	92,800	83,600	27.0	2,256,800	1,200	59.0	82,400	26.5
S. CENTRAL	295,500	272,200	26.5	7,216,500	4,200	53.0	268,000	26.1
Carter..........	40,500	37,000	30.1	1,113,400	0	0	37,000	30.1
Custer..........	36,500	32,000	25.2	806,400	800	38.0	31,200	24.9
Fallon..........	31,600	28,000	28.2	789,600	0	0	28,000	28.2
Powder River....	31,600	28,800	30.3	872,800	0	0	28,800	30.3
Prairie.........	41,300	34,800	27.3	949,800	200	35.0	34,600	27.2
Rosebud.........	53,500	42,900	24.3	1,040,900	200	35.0	42,700	24.2
Wibaux..........	15,900	14,600	26.0	379,600	0	0	14,600	26.0
S. EAST	250,900	218,100	27.3	5,952,500	1,200	37.0	216,900	27.2
STATE	2,700,000	2,480,000	27.0	66,960,000	19,000	56.0	2,461,000	26.8

Figure 39. Winter wheat production in Montana, 1984. Montana Crop and Livestock Reporting Service, 1985.

SPRING WHEAT OTHER THAN DURUM -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES — IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested	Yield Per Acre	Production -----Bushels-----	Acres Harvested	Yield Per Acre -Bu.-	Acres Harvested	Yield Per Acre -Bu.-
Deerlodge.......	300	300	26.0	7,800	0	0	300	26.0
Flathead........	900	900	62.0	55,800	900	62.0	0	0
Granite.........	300	300	25.0	7,500	0	0	300	25.0
Lake...........	3,100	3,000	49.6	148,700	2,400	56.0	600	23.7
Missoula........	500	500	57.2	28,600	400	64.0	100	30.0
Powell..........	500	500	28.0	14,000	0	0	500	28.0
Ravalli.........	1,300	1,300	57.0	74,100	1,300	57.0	0	0
Sanders.........	500	300	27.0	8,100	0	0	300	27.0
N. WEST	7,400	7,100	48.5	344,600	5,000	58.0	2,100	26.0
Blaine..........	71,400	65,500	19.0	1,245,400	3,500	38.0	62,000	17.9
Chouteau........	123,300	115,000	24.1	2,776,400	5,000	51.0	110,000	22.9
Glacier.........	115,200	91,500	10.3	938,900	1,300	37.0	90,200	9.9
Hill............	187,300	159,100	14.8	2,357,400	2,400	52.0	156,700	14.2
Liberty.........	118,700	112,200	12.1	1,358,600	500	38.0	111,700	12.0
Phillips........	84,600	78,400	16.5	1,291,900	3,100	36.0	75,300	15.7
Pondera.........	37,500	35,700	17.0	606,300	4,200	42.0	31,500	13.7
Teton...........	32,700	30,300	23.2	702,800	6,500	50.0	23,800	15.9
Toole...........	92,600	88,400	10.9	965,600	0	0	88,400	10.9
N. CENTRAL	863,300	776,100	15.8	12,243,300	26,500	45.0	749,600	14.7
Daniels.........	172,700	167,100	10.9	1,819,800	0	0	167,100	10.9
Dawson..........	65,000	61,900	18.9	1,168,100	0	0	61,900	18.9
Garfield........	40,000	34,000	12.4	421,700	400	50.0	33,600	12.0
McCone..........	90,900	88,200	22.0	1,938,800	3,100	53.0	85,100	20.9
Richland........	83,700	80,600	20.4	1,644,500	3,300	63.0	77,300	18.6
Roosevelt.......	201,300	193,400	14.9	2,888,400	4,200	58.0	189,200	14.0
Sheridan........	95,000	88,400	18.4	1,625,500	1,400	55.0	87,000	17.8
Valley..........	208,000	200,700	16.2	3,255,900	5,200	66.0	195,500	14.9
N. EAST	956,600	914,300	16.1	14,762,700	17,600	60.0	896,700	15.3
Broadwater......	11,300	10,800	47.4	512,000	6,600	63.0	4,200	22.9
Cascade.........	53,400	42,400	21.4	906,500	4,200	51.0	38,200	18.1
Fergus..........	14,600	12,500	14.4	180,100	300	53.0	12,200	13.5
Golden Valley...	900	900	24.4	22,000	300	48.0	600	12.7
Judith Basin....	11,100	10,700	17.7	189,100	100	57.0	10,600	17.3
Lewis & Clark...	1,600	1,600	38.3	61,200	800	60.0	800	16.5
Meagher.........	800	800	14.5	11,600	0	0	800	14.5
Musselshell.....	800	800	8.0	6,400	0	0	800	8.0
Petroleum.......	800	700	8.0	5,600	0	0	700	8.0
Wheatland.......	3,600	2,500	16.2	40,600	100	52.0	2,400	14.8
CENTRAL	98,900	83,700	23.1	1,935,100	12,400	58.0	71,300	17.1
Beaverhead......	6,000	5,900	54.5	321,800	5,100	59.0	800	26.1
Gallatin........	12,900	12,600	43.4	547,300	5,200	62.0	7,400	30.4
Jefferson.......	1,400	1,400	36.3	50,800	200	56.0	1,200	33.0
Madison.........	4,200	3,900	42.2	164,700	2,500	53.0	1,400	23.0
S. WEST	24,500	23,800	45.6	1,084,600	13,000	59.0	10,800	29.4
Big Horn........	20,200	19,800	31.8	630,100	5,100	62.0	14,700	21.4
Carbon..........	6,700	6,700	42.9	287,300	4,200	55.0	2,500	22.5
Park............	1,500	1,500	32.3	48,400	500	52.0	1,000	22.4
Stillwater......	3,900	3,900	19.1	74,500	100	59.0	3,800	18.1
Sweet Grass.....	300	300	30.3	9,100	100	52.0	200	19.5
Treasure........	3,000	3,000	50.3	150,900	2,100	65.0	900	16.0
Yellowstone.....	6,200	6,000	36.4	218,200	2,600	62.0	3,400	16.8
S. CENTRAL	41,800	41,200	34.4	1,418,500	14,700	60.0	26,500	20.2
Carter..........	5,600	5,200	17.7	91,800	0	0	5,200	17.7
Custer..........	10,500	10,300	31.4	323,000	1,700	59.0	8,600	25.9
Fallon..........	38,600	37,700	21.9	826,100	800	39.0	36,900	21.5
Powder River....	2,400	2,100	23.5	49,300	100	43.0	2,000	22.5
Prairie.........	2,300	2,200	18.1	39,800	0	0	2,200	18.1
Rosebud.........	8,700	8,400	24.7	207,600	1,200	61.0	7,200	18.7
Wibaux..........	39,400	37,900	21.1	798,600	0	0	37,900	21.1
S. EAST	107,500	103,800	22.5	2,336,200	3,800	55.0	100,000	21.3
STATE	2,100,000	1,950,000	17.5	34,125,000	93,000	55.0	1,857,000	15.6

Figure 40. Spring wheat production in Montana, 1984. Montana Crop and Livestock Reporting Service, 1985.

DURUM WHEAT -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested	Yield Per Acre	Production -----Bushels-----	Acres Harvested	Yield Per Acre -Bu.-	Acres Harvested	Yield Per Acre -Bu.-
Blaine..........	600	600	23.0	13,800	0	0	600	23.0
Chouteau........	3,600	3,500	25.4	89,000	0	0	3,500	25.4
Glacier.........	800	800	18.0	14,400	0	0	800	18.0
Hill............	400	400	16.0	6,400	0	0	400	16.0
Liberty.........	600	600	14.0	8,400	0	0	600	14.0
Phillips........	100	100	15.0	1,500	0	0	100	15.0
Pondera.........	19,400	18,800	19.9	373,200	1,200	67.0	17,600	16.5
Teton...........	3,300	3,300	28.9	95,500	800	62.0	2,500	18.4
Toole...........	22,100	21,300	17.8	379,400	0	0	21,300	17.8
N. CENTRAL	50,900	49,400	19.9	981,600	2,000	65.0	47,400	18.0
Daniels.........	4,300	3,900	15.8	61,600	0	0	3,900	15.8
Dawson..........	900	900	19.0	17,100	0	0	900	19.0
McCone..........	1,500	1,500	13.0	19,500	0	0	1,500	13.0
Richland........	900	900	18.0	16,200	0	0	900	18.0
Roosevelt.......	27,400	26,500	16.0	423,500	0	0	26,500	16.0
Sheridan........	123,300	121,300	16.1	1,949,200	600	52.0	120,700	15.9
Valley..........	2,100	2,000	16.0	32,000	0	0	2,000	16.0
N. EAST	160,400	157,000	16.0	2,519,100	600	52.0	156,400	15.9
Cascade.........	1,100	1,100	18.6	20,500	0	0	1,100	18.6
CENTRAL	1,100	1,100	18.6	20,500	0	0	1,100	18.6
Carter..........	100	100	19.0	1,900	0	0	100	19.0
Custer..........	100	100	20.0	2,000	0	0	100	20.0
Fallon..........	500	500	17.0	8,500	0	0	500	17.0
Wibaux..........	1,900	1,800	20.2	36,400	0	0	1,800	20.2
S. EAST	2,600	2,500	19.5	48,800	0	0	2,500	19.5
STATE	215,000	210,000	17.0	3,570,000	2,600	62.0	207,400	16.4

Figure 41. Durum production in Montana, 1984.
Montana Crop and Livestock Reporting Service, 1985.

BARLEY -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested	Yield Per Acre	Production	Acres Harvested	Yield Per Acre	Acres Harvested	Yield Per Acre
				------Bushels------		-Bu.-		-Bu.-
Deer Lodge......	2,400	2,400	54.3	130,200	1,500	67.0	900	33.0
Flathead........	31,300	30,500	59.5	1,814,700	20,000	69.0	10,500	41.4
Granite.........	600	500	68.0	34,000	500	68.0	0	0
Lake............	12,500	12,200	48.6	593,400	5,000	63.0	7,200	38.7
Lincoln.........	100	100	68.0	6,800	100	68.0	0	0
Mineral.........	100	100	34.0	3,400	0	0	100	34.0
Missoula........	3,600	3,500	51.5	180,400	2,500	60.0	1,000	30.4
Powell..........	6,200	6,100	54.4	332,000	3,200	70.0	2,900	37.2
Ravalli.........	6,100	5,800	60.6	351,600	4,200	73.0	1,600	28.1
Sanders.........	2,100	1,500	33.4	50,100	300	65.0	1,200	25.5
N.WEST	65,000	62,700	55.8	3,496,600	37,300	68.0	25,400	37.8
Blaine..........	67,000	57,200	25.8	1,475,700	3,100	50.0	54,100	24.4
Chouteau........	290,700	260,100	28.6	7,433,300	1,200	50.0	258,900	28.5
Glacier.........	123,000	91,500	19.3	1,769,400	7,500	54.0	84,000	16.2
Hill............	109,700	96,300	19.5	1,877,500	2,000	62.0	94,300	18.6
Liberty.........	103,000	85,000	14.4	1,225,800	0	0	85,000	14.4
Phillips........	50,400	45,400	22.8	1,035,200	2,000	51.0	43,400	21.5
Pondera.........	156,700	145,700	29.1	4,233,500	21,600	61.0	124,100	23.5
Teton...........	139,800	136,100	36.3	4,938,000	41,500	62.0	94,600	25.0
Toole...........	101,500	91,700	17.4	1,591,200	300	52.0	91,400	17.2
N. CENTRAL	1,141,800	1,009,000	25.4	25,579,600	79,200	60.0	929,800	22.4
Daniels.........	42,000	34,700	14.6	506,400	0	0	34,700	14.6
Dawson..........	39,200	34,700	26.3	911,600	400	52.0	34,300	26.0
Garfield........	28,400	25,000	17.6	439,300	100	63.0	24,900	17.4
McCone..........	36,000	32,900	26.6	874,200	300	56.0	32,600	26.3
Richland........	31,700	28,700	27.4	785,800	1,100	69.0	27,600	25.7
Roosevelt.......	44,400	39,600	17.9	710,000	700	54.0	38,900	17.3
Sheridan........	47,100	42,400	18.0	764,100	0	0	42,400	18.0
Valley..........	86,800	81,200	18.8	1,525,400	1,400	56.0	79,800	18.1
N. EAST	355,600	319,200	20.4	6,516,800	4,000	59.0	315,200	19.9
Broadwater......	19,500	19,000	43.7	831,100	7,400	62.0	11,600	32.1
Cascade.........	84,300	82,700	30.0	2,480,800	11,300	61.0	71,400	25.1
Fergus..........	148,800	143,400	24.3	3,487,500	1,200	46.0	142,200	24.1
Golden Valley...	13,800	13,300	17.3	229,800	700	54.0	12,600	15.2
Judith Basin....	89,800	86,500	28.3	2,451,700	2,400	43.0	84,100	27.9
Lewis & Clark...	11,400	9,900	43.2	427,300	5,000	58.0	4,900	28.0
Meagher.........	20,400	20,400	25.1	511,700	1,800	49.0	18,600	22.8
Musselshell.....	12,000	9,500	18.2	173,100	700	47.0	8,800	15.9
Petroleum.......	5,000	4,200	17.2	72,400	300	57.0	3,900	14.2
Wheatland.......	17,300	15,600	16.2	253,200	1,200	43.0	14,400	14.0
CENTRAL	422,300	404,500	27.0	10,918,600	32,000	57.0	372,500	24.4
Beaverhead......	15,400	13,900	44.6	620,100	7,700	63.0	6,200	21.8
Gallatin........	65,200	62,600	55.0	3,444,800	22,800	75.0	39,800	43.6
Jefferson.......	2,700	2,300	46.9	107,900	900	67.0	1,400	34.0
Madison.........	11,300	10,300	62.6	644,300	7,500	73.0	2,800	34.6
Silver Bow......	300	300	65.0	19,500	300	65.0	0	0
S. WEST	94,900	89,400	54.1	4,836,600	39,200	72.0	50,200	40.1
Big Horn........	40,900	40,600	32.9	1,335,800	4,100	72.0	36,500	28.5
Carbon..........	15,900	15,500	50.1	776,100	6,900	79.0	8,600	26.9
Park............	16,300	15,700	36.3	569,400	2,900	69.0	12,800	28.9
Stillwater......	26,400	25,900	30.0	777,700	1,300	77.0	24,600	27.5
Sweet Grass.....	6,200	5,000	32.9	164,400	1,000	66.0	4,000	24.6
Treasure........	2,800	2,800	68.9	192,900	2,300	78.0	500	27.0
Yellowstone.....	50,700	48,700	36.5	1,777,700	10,000	78.0	38,700	25.8
S. CENTRAL	159,200	154,200	36.3	5,594,000	28,500	76.0	125,700	27.3
Carter..........	9,500	8,300	32.8	272,500	0	0	8,300	32.8
Custer..........	7,700	6,500	29.8	193,900	800	73.0	5,700	23.8
Fallon..........	13,800	12,600	34.7	437,500	0	0	12,600	34.7
Powder River....	8,600	7,900	26.2	207,100	0	0	7,900	26.2
Prairie.........	15,500	13,700	25.6	351,200	1,300	52.0	12,400	22.9
Rosebud.........	17,600	15,900	29.9	476,100	2,700	60.0	13,200	23.8
Wibaux.........	8,500	6,100	32.7	199,500	0	0	6,100	32.7
S. EAST	81,200	71,000	30.1	2,137,800	4,800	60.0	66,200	27.9
STATE	2,320,000	2,110,000	28.0	59,080,000	225,000	65.0	1,885,000	23.6

Figure 42. Barley production in Montana, 1984.
Montana Crop and Livestock Reporting Service, 1985.

OATS -- 1984

ACREAGE, YIELD and PRODUCTION BY COUNTIES -- IRRIGATED and NOT IRRIGATED

COUNTY & DISTRICT	TOTAL				IRRIGATED		NOT IRRIGATED	
	Acres Planted	Acres Harvested For Grain	Yield Per Acre	Production	Acres Harvested	Yield Per Acre	Acres Harvested	Yield Per Acre
				---------Bu.---------		-Bu.-		-Bu.-
Deer Lodge......	0	0	0	0	0	0	0	0
Flathead........	1,800	900	36.9	33,200	500	48.0	400	23.0
Granite.........	300	200	45.0	9,000	200	45.0	0	0
Lake............	2,800	2,400	54.3	130,400	2,000	60.0	400	26.0
Lincoln.........	400	200	43.0	8,600	200	43.0	0	0
Mineral.........	400	100	34.0	3,400	0	0	100	34.0
Missoula........	1,300	1,000	46.0	46,000	600	60.0	400	25.0
Powell..........	1,000	800	40.0	32,000	400	55.0	400	25.0
Ravalli.........	1,700	1,200	56.5	67,800	1,000	63.0	200	24.0
Sanders.........	1,800	800	40.3	32,200	500	50.0	300	24.0
N.WEST	11,500	7,600	47.7	362,600	5,400	57.0	2,200	25.0
Blaine..........	8,800	3,100	34.0	105,300	1,000	57.0	2,100	23.0
Chouteau........	5,500	2,900	23.0	66,800	100	52.0	2,800	22.0
Glacier.........	2,500	1,000	31.2	31,200	200	56.0	800	25.0
Hill...........	9,200	1,700	30.9	52,600	400	47.0	1,300	26.0
Liberty.........	2,300	500	22.0	11,000	0	0	500	22.0
Phillips........	15,000	2,900	30.8	89,300	700	49.0	2,200	25.0
Pondera.........	1,700	1,300	32.5	42,300	300	51.0	1,000	27.0
Teton...........	2,200	1,500	26.2	39,300	200	47.0	1,300	23.0
Toole...........	2,300	1,500	26.5	39,800	100	48.0	1,400	25.0
N. CENTRAL	49,500	16,400	29.1	477,600	3,000	52.0	13,400	24.0
Daniels.........	6,100	1,200	23.0	27,600	0	0	1,200	23.0
Dawson..........	5,800	3,200	31.5	100,800	200	69.0	3,000	29.0
Garfield........	8,100	3,000	20.0	60,000	0	0	3,000	20.0
McCone..........	6,000	2,600	22.4	58,200	100	57.0	2,500	21.0
Richland........	10,700	6,300	37.2	234,100	1,000	70.0	5,300	31.0
Roosevelt.......	11,700	3,900	26.2	102,300	500	55.0	3,400	22.0
Sheridan........	10,900	3,500	26.1	91,300	400	50.0	3,100	23.0
Valley..........	9,400	4,000	25.8	103,100	100	56.0	3,900	25.0
N.EAST	68,700	27,700	28.1	777,400	2,300	62.0	25,400	25.0
Broadwater......	1,500	1,200	61.5	73,800	1,000	68.0	200	29.0
Cascade.........	3,800	1,900	29.8	56,600	400	44.0	1,500	26.0
Fergus..........	8,600	4,000	31.7	126,600	200	44.0	3,800	31.0
Golden Valley...	3,700	2,100	29.3	61,500	400	56.0	1,700	23.0
Judith Basin....	5,000	3,300	31.4	103,600	100	44.0	3,200	31.0
Lewis & Clark...	2,000	1,400	58.0	81,200	1,400	58.0	0	0
Meagher.........	2,500	1,200	36.0	43,200	600	45.0	600	27.0
Musselshell.....	3,600	2,000	37.3	74,600	900	56.0	1,100	22.0
Petroleum.......	1,200	400	41.3	16,500	300	47.0	100	24.0
Wheatland.......	1,400	900	29.0	26,100	200	43.0	700	25.0
CENTRAL	33,300	18,400	36.1	663,700	5,500	55.0	12,900	28.0
						0	0	0
Beaverhead......	1,800	1,000	69.5	69,500	700	80.0	300	45.0
Gallatin........	2,800	2,200	61.5	135,300	1,300	75.0	900	42.0
Jefferson.......	2,400	800	49.3	39,400	600	56.0	200	29.0
Madison.........	3,800	800	63.1	50,500	700	68.0	100	29.0
Silver Bow......	200	100	67.0	6,700	100	67.0	0	0
S.WEST	11,000	4,900	61.5	301,400	3,400	71.0	1,500	40.0
Big Horn........	2,300	2,000	46.0	92,000	200	82.0	1,800	42.0
Carbon..........	1,900	1,300	56.2	73,100	800	72.0	500	31.0
Park............	1,500	1,100	62.6	68,900	900	69.0	200	34.0
Stillwater......	1,500	1,200	38.5	46,200	200	76.0	1,000	31.0
Sweet Grass.....	3,000	1,500	53.5	80,200	800	67.0	700	38.0
Treasure........	500	500	74.6	37,300	400	82.0	100	45.0
Yellowstone.....	2,800	2,700	35.9	96,800	400	81.0	2,300	28.0
S.CENTRAL	13,500	10,300	48.0	494,500	3,700	73.0	6,600	34.0
Carter..........	4,500	2,500	35.0	87,500	0	0	2,500	35.0
Custer..........	4,600	3,100	46.9	145,400	1,300	62.0	1,800	36.0
Fallon..........	4,800	2,400	39.9	95,800	200	50.0	2,200	39.0
Powder River....	3,700	3,200	41.0	131,300	300	51.0	2,900	40.0
Prairie.........	4,200	2,000	39.5	79,000	300	65.0	1,700	35.0
Rosebud.........	2,500	2,300	43.2	99,400	1,500	46.0	800	38.0
Wibaux..........	8,200	4,200	40.3	169,400	100	54.0	4,100	40.0
S.EAST	32,500	19,700	41.0	807,800	3,700	54.0	16,000	38.0
STATE	220,000	105000	37.0	3,885,000	27,000	60.0	78,000	29.0

Figure 43. Oats production in Montana, 1984.
Montana Crop and Livestock Reporting Service,
1985.

Appendix B

Wood Inventory

Tree Species Native To Montana

Coniferous	Deciduous
Grand fir	Boxelder
Subalpine fir	Paper birch
Utah juniper	Green ash
Rocky Mountain juniper	Balsam poplar
Subalpine larch	Eastern cottonwood
Western larch	Black cotton wood
Engelmann spruce	Quaking aspen
White spruce	Casara buckthorn
Whitebark pine	Peachleaf willow
Lodgepole pine	American elm
Limber pine	
Western white pine	
Ponderosa pine	
Douglas-fir	
Western red cedar	
Western hemlock	
Mountain hemlock	

Species	Ownership				Total
	National Forest	Other public	Forest industry	Farmer and other private	

GROWING STOCK

- - - - - - - - - Million cubic feet - - - - - - - - - -

Douglas-fir	4,623.6	412.4	1,003.7	1,407.7	7,447.4
Ponderosa pine	785.7	192.8	287.4	901.7	2,167.6
Western white pine	186.2	9.7	22.1	4.8	222.8
Lodgepole pine	6,660.6	280.9	641.4	787.5	8,370.4
Whitebark-limber pine	611.2	25.7	43.3	87.2	767.4
Western larch	1,503.8	138.6	394.8	141.5	2,178.7
Grand fir	306.7	23.9	101.0	19.7	451.3
Subalpine fir	1,330.0	61.0	101.5	95.4	1,587.9
Engelmann spruce	1,554.2	69.1	176.1	157.7	1,957.1
Western hemlock	293.7	0.5	13.4	7.0	314.6
Western redcedar	233.2	7.7	28.4	13.6	282.9
Other softwoods	0.6	--	--	--	0.6
Total softwoods	18,089.5	1,222.3	2,813.1	3,623.8	25,748.7
Aspen	20.3	12.4	8.4	106.5	147.6
Cottonwood	--	26.3	10.5	185.0	221.8
Other hardwoods	25.7	5.8	3.1	13.3	47.9
Total hardwoods	46.0	44.5	22.0	304.8	417.3
All species	18,135.5	1,266.8	2,835.1	3,928.6	26,166.0

SAWTIMBER

- - - Million board feet, International ¼-inch rule - - -

Douglas-fir	17,035.4	1,615.4	3,924.1	4,911.8	27,486.7
Ponderosa pine	3,427.5	792.9	1,532.0	3,367.8	9,120.2
Western white pine	907.8	49.1	110.1	17.8	1,084.8
Lodgepole pine	15,094.1	634.3	1,098.3	1,842.2	18,668.9
Whitebark-limber pine	2,015.8	107.5	186.6	294.3	2,604.2
Western larch	6,533.5	740.4	2,024.7	533.4	9,832.0
Grand fir	1,212.3	88.7	387.2	65.9	1,754.1
Subalpine fir	4,205.0	156.9	248.7	198.1	4,808.7
Engelmann spruce	6,931.6	304.3	831.8	621.7	8,689.4
Western hemlock	1,337.1	1.1	41.2	22.1	1,401.5
Western redcedar	1,358.6	32.0	119.0	48.6	1,558.2
Other softwoods	2.3	--	--	--	2.3
Total softwoods	60,061.0	4,522.6	10,503.7	11,923.7	87,011.0
Aspen	28.5	18.6	12.5	163.4	223.0
Cottonwood	--	112.3	42.4	796.2	950.9
Other hardwoods	56.0	8.9	6.4	8.4	79.7
Total hardwoods	84.5	139.8	61.3	968.0	1,253.6
All species	60,145.5	4,662.4	10,565.0	12,891.7	88,264.6

Figure. 44 Net volume of growing stock and sawtimber on commercial timberland in Montana, 1980. A. W. Green et al. 1985.

Appendix C

Economic Spreadsheet Program

This computer program is designed to evaluate preliminary economic feasibility of a particular biomass gasifier installation. The program uses LOTUS-123 release 2.0 or greater as supporting software on an IBM PC or any 100% IBM compatible computer. LOTUS-123 is used because of its excellent spreadsheet capabilities. To operate the program follow the following procedures.

Start-up

1. For a computer equipped with a dual floppy drive system, insert the LOTUS-123 SYSTEM DISK into disk drive A and the biomass gasification economic feasibility disk into drive B. For a computer equipped with a hard drive with the LOTUS-123 software resident on it, just insert the biomass gasification economic feasibility disk into drive A.

2. Invoke the LOTUS-123 software by typing lotus. The system will then display a LOTUS-123 menu screen showing various features of lotus. To continue on push <RETURN>.

3. The economic spreadsheet will automatically load and start to execute. If the spreadsheet does not load automatically type "/FR A:BIOECON" <RETURN> and the spreadsheet will load and start execution.

4. Press the "cap lock" key to set the input to upper case. The spreadsheet is case sensitive, so if errors develop while executing the program try restarting with the

"cap lock" key on.

Using The Economic Spreadsheet

The spreadsheet is menu driven to allow for easy use. The menu is displayed at the top of the screen. The menu includes the following options:

A. INPUT Allows for input and execution of program.

B. VIEW Exits the menu to allow for viewing.

C. PRINT-SPREADSHEET Prints the whole spreadsheet.

D. PRINT-SUMMARY Prints economic summary.

E. GRAPH Graphs the net present value after taxes.

F. EXIT Exits spreadsheet.

To select the desired option move the cursor, using the cursor control keys until it overlays the desired option and then press <RETURN>.

INPUT Option

When the "INPUT" option is invoked the cursor will move to the first cell where user input is required. The user has the option of entering in new data or pressing <RETURN> to leave the cell the same. After the return key is pressed the cursor is then moved to the next cell requiring user input. The INPUT option steps the user through the spreadsheet asking for input and also executing segments of the spreadsheet when required. When the INPUT option has finished executing, the spreadsheet menu is again displayed

at the top of the screen.

VIEW Option

To enable the user to move freely around the spreadsheet and view its contents, move the cursor so it overlays the "VIEW" option and press <RETURN>. To re-invoke the spreadsheet menu press the "ALT M" keys and the menu will appear at the top of the screen.

PRINT-SPREADSHEET Option

The "PRINT-SPREADSHEET" menu option allows the user to print out the entire spreadsheet. The size of print is compressed in order to fit the spreadsheet onto an 80-column printer.

PRINT-SUMMARY Option

The "PRINT-SUMMARY" menu option allows the user to print out the spreadsheet economic summary. The print is compressed.

GRAPH Option

The "GRAPH" menu option allows the user to quickly assess the economics of a particular biomass gasification site in terms of net present value after taxes. This option should only be used after the assessment of the current user inputs.

EXIT Option

The "EXIT" menu option allows the user to exit the

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spreadsheet program and LOTUS-123.

Program Documentation

The biomass economic spreadsheet program is partitioned into several parts according to the main operation of that part. The segments of the program are as follows:

1. user input;
2. projected income;
3. projected expenses;
4. fuel displacement credit;
5. cash flow projection before taxes;
6. projected taxes;
7. cash flow projection after taxes; and
8. economic summary.

User Input

The user input operation is set up to step the user through the required information needed to assess the economics of a particular biomass gasification system. Initially the user is asked to give information on the type of system, its application and location to be used for bookkeeping reasons only. The spreadsheet then proceeds to inquire about the type of gasifier used, the type of feedstock, and the energy capacity of the system. The input labeled "MECHANICAL CAPACITY" pertains to the use of an internal combustion engine to produce shaft power. In the case of cogeneration (where more than one energy form is

produced) the gasification system will be sized to the smallest size possible while still meeting the energy output requirements.

After the system hour inputs are filled the input procedure is halted in order to calculate a suggested gasifier size. The suggested size is then transferred to the cell labeled "USER'S INSTALLED SIZE", and the user then has the option to change the size or not. Again the input procedure is halted in order to calculate the suggested installed cost. This installed cost is only a rough estimate because the system requirements for each gasification site are different. The suggested installed cost estimate is then transferred to the cell labeled "USER'S INSTALLED COST" and again the user has the option to change the cost or not.

The input procedure then continues to prompt the user for economic information and operational cost information. When the procedure reaches the fuel displacement credit segment, the user is given the option of entering up to two displaced fuel types. If no conventional fuel types are displaced, the respective cells should be filled with "N/A". The user is also asked under the fuel displacement credit if the fuel displacement credit is to be used in calculating taxable income.

The next input segment labeled "CURRENT FUEL COSTS" are the conventional fuel costs used by the program to calculate the fuel displacement credit. The following segment labeled

"IF ELECTRICITY IS PRODUCED" by the system is used to calculate the income produced by selling the generated electricity back to the utility. The remainder of the input procedure is straight-forward and following its completion the spreadsheet results are calculated.

Projected Income

The selling of generated electricity back to the utility and the salvage value of the system are considered to be the only two sources of income. The income from electricity is calculated only if the user input includes an electrical capacity and is used for utility purposes.

Projected Expenses

The projected expenses include separate parts for deductible items and non-deductible items. The deductible items include depreciation, interest, and operational costs. Depreciation is calculated using the straight line method. The non-deductible items include both initial investment and loan principal.

The term total expense includes the sum of both the deductible and non-deductible, while the total cash outlay includes the total expenses minus depreciation.

Fuel Displacement Credit

The fuel displacement credit is the amount of savings gained by using energy generated by the gasification system

rather than conventional alternatives. For example, if the
system produces electricity and/or heat energy for personal
use, the savings generated are termed a fuel displacement
credit.

Cash Flow Projection Before Taxes

The cash flows before taxes include cash sale income,
fuel displacement credit, and total cash outlay. The
summation of the above cash flows is termed the net yearly
cash flow. From the net yearly cash flow, the cumulative
cash flow without the initial investment, the cumulative
cash flow with the initial investment, and the net present
values are calculated.

Projected Taxes

The taxable income includes the cash sale income plus
the fuel displacement credit minus the deductible items. The
user is given the option in the input to include the fuel
displacement credit as taxable income or not.

Cash Flow Projection After Taxes

The procedure for calculating the cash flow after taxes
is the same as stated early in the before taxes case, except
now the income tax is treated as a cash flow. The cumulative
cash flows and net present values are calculated.

Economic Summary

The economic summary allows the user to quickly assess

results of the economic spreadsheet, without having to shuffle through intermediate calculations. The summary includes the time and date the input system information was executed, bookkeeping information such as the system size etc., and cash flow information before and after taxes. The summary also shows the rate of return for both the before and after tax cases, the cost of energy production ($/MBTU), and the equivalent conventional fuel costs.

The cost of energy production was calculated using the total expenses divided by the system's energy output. The equivalent conventional fuel costs are calculated by converting the cost of energy production to the appropriate unit ($/KWH) with a conversion efficiency of 100%.

```
**********************************************************************************************************************
                              BIOMASS GASIFICATION ECONOMIC SPREADSHEET
                                    BY CLINTON MOLDE    1/29/87
**********************************************************************************************************************
USER INPUT
**********

SYSTEM:               DOWNDRAFT GASIFIER/ENGINE SYSTEM
APPLICATION:          IRRIGATION PUMPING
LOCATION:             ON-FARM

GASIFIER TYPE:        DD      (DD OR FB)
FEEDSTOCK TYPE:       WOOD    (STRAW OR WOOD)
MECHANICAL CAPACITY:       300 HORSEPOWER
HEAT CAPACITY:               0 BTU/HOUR
ELECTRIC CAPACITY:           0 kW
SYSTEM HOURS:             1500 HOURS/YEAR
SYSTEM HOURS:               20 HOURS/DAY

SUGGESTED GASIFER SIZE:   3819600 BTU/HOUR
USER'S GASIFIER SIZE:     3819600 BTU/HOUR

SUGGESTED INSTALLED COST:  100000 DOLLARS
USER'S INSTALLED COST:     100000 DOLLARS

INTIAL INVESTMENT:          20 PERCENT
SYSTEM LIFE:                10 YEARS
SALVAGE VALUE:               0 DOLLARS
LOAN RATE:                   8 PERCENT/YEAR
LOAN SCHEDULE:               5 YEARS
TAXES FEDERAL:              30 PERCENT
TAXES STATE:                 7 PERCENT
DISCOUNT RATE:              12 PERCENT

OPERATIONAL COSTS:
   SUPPLY COST:              1 PERCENT OF INSTALLED COST
      COST INCREASE:         5 PRECENT/YEAR
   REPAIR & MAINT.:          2 PERCENT OF INSTALLED COST
      COST INCREASE:         6 PRECENT/YEAR
   INSURANCE:                1 PERCENT OF INSTALLED COST
      COST INCREASE:         6 PRECENT/YEAR
   LABOR COST:              20 DOLLARS/DAY
      COST INCREASE:         5 PRECENT/YEAR

FEEDSTOCK COST:           2.00 DOLLARS/MBTU ($0 TO $5)
   COST INCREASE:            2 PRECENT/YEAR

FUEL DISPLACMENT CREDIT:
   TYPE DISPLACED (1ST):  ELEC.   (ELEC., NG, LPG, FUEL OIL, COAL, N/A)
   TYPE DISPLACED (2ND):  N/A     (ELEC., NG, LPG, FUEL OIL, COAL, N/A)
   COST INCREASE:            5 PRECENT/YEAR
   TAXABLE INCOME ?:      NO      (YES OR NO)

CURRENT FUEL COSTS:
        ELEC.   (UTILITY) 0.0310 DOLLARS/KWH
        NG                3.0400 DOLLARS/MCF
```

Figure 45. Economic spreadsheet program.

```
          LPG              0.6500 DOLLARS/GALLON
          FUEL OIL         0.7000 DOLLARS/GALLON
          COAL             20.00 DOLLARS/TON

IF ELECTRICY IS PRODUCED:
    USED FOR:             N/A    (PERSONAL, UTILITY OR N/A) PURPOSES
    BUYBACK RATE:         0.0130 DOLLARS/KWH
    COST INCREASE:           5 PERCENT/YEAR

TAXES:
    PROPERTY TAXES:          1 PERCENT
    FED. INVEST TAX CREDIT: 10 PERCENT
      NUMBER OF YEARS:       1 YEARS
    FED. ENERGY CREDIT:      0 PRECENT
      NUMBER OF YEARS:       0 YEARS
    STATE ENERGY CREDIT:     0 PRECENT
      NUMBER OF YEARS:       0 YEARS
```

****

PROJECTED INCOME:
****

	% YEARLY INCREASE	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
ELECTRICITY	5	0	0	0	0	0	0	0	0	0	0	0
SALVAGE VALUE	---	0	0	0	0	0	0	0	0	0	0	0
TOTAL INCOME		0	0	0	0	0	0	0	0	0	0	0

****

PROJECTED EXPENSES:
****

	% YEARLY INCREASE	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
DEDUCTABLE ITEMS:												
DEPRECIATION	---	0	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
INTEREST	---	0	6400	5309	4131	2858	1484	0	0	0	0	0
SUPPLY COSTS	5	0	1000	1050	1103	1158	1216	1276	1340	1407	1477	1551
REPAIR & MAINT.	6	0	2000	2120	2247	2382	2525	2676	2837	3007	3188	3379
INSURANCE	6	0	1000	1060	1124	1191	1262	1338	1419	1504	1594	1689
PROPERTY TAXES	---	0	900	800	700	600	500	400	300	200	100	0
FEEDSTOCK	2	0	16370	16697	17031	17372	17719	18073	18435	18804	19180	19563
LABOR	5	0	1500	1575	1654	1736	1823	1914	2010	2111	2216	2327
SUM OF DEDUCTABLE ITEMS		0	39170	38611	37989	37297	36529	35679	36341	37032	37755	38510
NONDEDUCTABLE ITEMS:												
INITIAL INVEST	---	20000	---	---	---	---	---	---	---	---	---	---
PRINCIPAL ON LOAN	---	0	13637	14727	15906	17178	18552	0	0	0	0	0
SUM OF NONDEDUCTABLE ITEMS		20000	13637	14727	15906	17178	18552	0	0	0	0	0
SUM OF DEDUCTABLE ITEMS		0	39170	38611	37989	37297	36529	35679	36341	37032	37755	38510
SUM OF NONDEDUCTABLE ITEMS		20000	13637	14727	15906	17178	18552	0	0	0	0	0

		-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
TOTAL EXPENSES	20000	52806	53339	53895	54475	55082	35679	36341	37032	37755	38510
TOTAL CASH OUTLAYS	20000	42806	43339	43895	44475	45082	25679	26341	27032	27755	28510

****

FUEL DISPLACEMENT CREDIT:
****

	% YEARLY INCREASE	TEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
EST. FUEL DISPLACEMENT	5	0	10408	10928	11475	12048	12651	13283	13948	14645	15377	16146

****

CASH FLOW PROJECTION BEFORE TAXES:
****

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
CASH SALES	0	0	0	0	0	0	0	0	0	0	0
FUEL DISPLACEMENT CREDIT	0	10408	10928	11475	12048	12651	13283	13948	14645	15377	16146
TOTAL RECEIPTS	0	10408	10928	11475	12048	12651	13283	13948	14645	15377	16146
TOTAL OUTLATS	20000	42806	43339	43895	44475	45082	25679	26341	27032	27755	28510
NET YEARLY CASH FLOW	-20000	-32398	-32410	-32420	-32427	-32431	-12395	-12393	-12387	-12378	-12364
CUMM. CASH FLOW W/O INIT. INVEST.	---	-32398	-64809	-97228	-129655	-162086	-174482	-186875	-199262	-211640	-224004
CUMM. CASH FLOW WITH INIT. INVEST	-20000	-52398	-84809	-117228	-149655	-182086	-194482	-206875	-219262	-231640	-244004
NET PRESENT VALUE	-20000	-48927	-74764	-97840	-118448	-136850	-143130	-148736	-153739	-158203	-162183

****

PROJECTED TAXES:
****

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
NET TAXABLE INCOME	0	-39170	-38611	-37989	-37297	-36529	-35679	-36341	-37032	-37755	-38510
NET FED. TAX (- SAVING)	0	-11751	-11583	-11397	-11189	-10959	-10704	-10902	-11110	-11326	-11553
NET STATE TAX (- SAVING)	0	-2742	-2703	-2659	-2611	-2557	-2498	-2544	-2592	-2643	-2696
FED. INVEST TAX CREDIT	0	-10000	0	0	0	0	0	0	0	0	0
FED. ENERGY CREDIT	0	0	0	0	0	0	0	0	0	0	0
STATE ENERGY CREDIT	0	0	0	0	0	0	0	0	0	0	0
TOTAL TAX	0	-24493	-14286	-14056	-13800	-13516	-13201	-13446	-13702	-13969	-14249

****

CASH FLOW PROJECTION AFTER TAXES:
****

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
CASH SALES	0	0	0	0	0	0	0	0	0	0	0
FUEL DISPLACEMENT CREDIT	0	10408	10928	11475	12048	12651	13283	13948	14645	15377	16146
INCOME TAX (+ CREDIT)	0	24493	14286	14056	13800	13516	13201	13446	13702	13969	14249
TOTAL RECEIPTS	0	34901	25214	25531	25848	26167	26485	27394	28347	29347	30395
TOTAL OUTLATS	20000	42806	43339	43895	44475	45082	25679	26341	27032	27755	28510

```
NET YEARLY CASH FLOW               -20000   -7906  -18124  -18364  -18627  -18915     806    1053    1315    1592    1885
CUMM. CASH FLOW W/O INIT. INVEST.     ---   -7906  -26030  -44394  -63020  -81935  -81130  -80077  -78762  -77170  -75286
CUMM. CASH FLOW WITH INIT. INVEST  -20000  -27906  -46030  -64394  -83020 -101935 -101130 -100077  -98762  -97170  -95286
NET PRESENT VALUE                  -20000  -27058  -41507  -54578  -66416  -77149  -76740  -76264  -75733  -75159  -74552
```

****

ECONOMIC SUMMARY:
****

TIME: 22:16:40
DATE: 06/14/87

SYSTEM: DOWNDRAFT GASIFIER/ENGINE SYSTEM
APPLICATION: IRRIGATION PUMPING
LOCATION: ON-FARM

GASIFIER TYPE: DOWNDRAFT
GASIFIER SIZE: 3819600 BTU/HOUR
SYSTEM COST: 100000 DOLLARS
TYPE OF FEEDSTOCK USED: WOOD
FEEDSTOCK REQUIRED: 512 TONS/YEAR

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
BEFORE TAXES:											
NET YEARLY CASH FLOW:	-20000	-32398	-32410	-32420	-32427	-32431	-12395	-12393	-12387	-12378	-12364
CUMM. CASH FLOW W/ INITIAL INVEST.:	-20000	-52398	-84809	-117228	-149655	-182086	-194482	-206875	-219262	-231640	-244004
NET PRESENT VALUE:	-20000	-48927	-74764	-97840	-118448	-136850	-143130	-148736	-153739	-158203	-162183
RETURN ON INVESTMENT:	-199.01%										
AFTER TAXES:											
NET YEARLY CASH FLOW:	-20000	-7906	-18124	-18364	-18627	-18915	806	1053	1315	1592	1885
CUMM. CASH FLOW W/ INITIAL INVEST.:	-20000	-27906	-46030	-64394	-83020	-101935	-101130	-100077	-98762	-97170	-95286
NET PRESENT VALUE:	-20000	-27058	-41507	-54578	-66416	-77149	-76740	-76264	-75733	-75159	-74552
RETURN ON INVESTMENT:	-39.07%										

	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10
COST PER MBTU:	0.00	9.22	9.31	9.41	9.51	9.61	6.23	6.34	6.46	6.59	6.72
EQUIVALENT FUEL COSTS:											
ELEC.-UTILITY (DOLLARS/KWH):	0.0000	0.0315	0.0318	0.0321	0.0325	0.0328	0.0213	0.0216	0.0221	0.0225	0.0229
NG (DOLLARS/MCF):	0.0000	8.30	8.38	8.47	8.56	8.65	5.60	5.71	5.82	5.93	6.05
LPG (DOLLARS/GALLON):	0.0000	0.86	0.87	0.87	0.88	0.89	0.58	0.59	0.60	0.61	0.63
FUEL OIL (DOLLARS/GALLON):	0.0000	1.30	1.31	1.33	1.34	1.36	0.88	0.89	0.91	0.93	0.95
COAL (DOLLARS/TON):	0.0000	184.33	186.19	188.13	190.16	192.28	124.55	126.86	129.27	131.79	134.43

****
****

Appendix D

Literature Review

The annotated bibliography contains both current and historical published material pertinent to the subject of gasification of agricultural residues and the applications of the energy produced. Also, some information on gasification of wood is presented because of its on-farm applications. The structure of the bibliographies in most cases closely follows the structure shown below.

List of authors, with the principal author first.

Title.

The responsible organization.

Source of publication.

Short summary of what is contained in the report, paper, or text.

The annotated bibliographies were placed into a computerized database, for quick and easy access. The directions for the use of the database are as follows:

Computer Database

This database is designed to search for specific annotated bibliographies using specific criteria. The database uses LOTUS 123 as supporting software on an IBM PC or any 100% IBM compatible computer. To operate the database follow the following procedures.

Start-up

1.   For a computer equipped with a dual floppy drive system

insert the LOTUS 123 SYSTEM DISK into disk drive A and the Bibliography disk into drive B. Turn on the computer.

2.   The system will request a new time and a new date to be entered. If the displayed date or time are incorrect then type in the correct time or date following the dislayed format. The input can be ignored by pressing <RETURN> each time.

3.   The system will then display a LOTUS 123 menu screen showing various features of LOTUS. To continue on the right track push <RETURN>.

4.   The system will then display a LOTUS introduction screen; any key can then be pushed to continue. The database program will then automatically load and start to execute.

Using the Database

The bibliography database on the gasification of agricultural residues was set up on the computer to allow for a quick and easy literature search over a large number of different areas.

The program is menu driven and begins by displaying an introduction screen which shows a general overview of the contents of the database. The prompt at the bottom of the screen is used to request the select an option from the menu at the top of the screen. The options that can be selected include:

A. SELECT   Accesses the search criteria menu.

B. VIEW   Views the requested bibliography.

C. PRINT   Prints the requested bibliography.

D. OUTPUT   Returns to the selected output.

E. UP   Pages the screen up.

F. DOWN   Pages the screen down.

G. QUIT   Returns control to the system.

1.   To select the desired option move the cursor, using the cursor control keys until it overlays the desired option and then press <RETURN>.

Starting A Search

1.   To start a search move the cursor so it overlays the SELECT option and press <RETURN>.

When the SELECT option is invoked the select criteria menu is displayed at the top of the screen. This menu contains the following options:

A. TITLE   Selects bibliographies by title.

B. YEARS   Selects bibliographies by years.

C. AUTHORS   Selects bibliographies by authors.

D. KEYWORDS Selects bibliographies by keywords.

E. RETURN   Returns to the main menu.

Every bibliography within the database has a maximum of five keywords associated with it. In some cases more than five could have been used, but the number was kept to the five most descriptive keywords. Each select criteria option when chosen displays a prompt screen which states specific rules to follow for that option.

2.   The select criteria menu now is displayed at the top of
the screen. Move the cursor to the proper criteria option
and again press <RETURN>.

3.   For each criteria option a prompt will appear at the
top of the screen asking for search input. Each option will
accept a maximum of five search words, except for the TITLE
option which only allows for one title input. If a search is
using less than five search words, the remaining inputs are
by-passed by using <RETURN>. Remember to follow any specific
rules displayed.

        The program then searches the database bibliographies
for the search criteria, eliminating any duplicates. The
program then displays the output bibliographies's file
numbers and titles and returns the main menu.

Operations On Selected Bibliographies

        When the search is finished, the program displays all
the file numbers and titles of the bibliographies in the
data base that meet the requirements of the search. This is
called the output.

    VIEW Option

        When this option is invoked, a prompt appears at the
top of the screen asking for the file number you want to
view. The desired file number from the selection output is
then entered and <RETURN> pressed to view the bibliography.
After reading the bibliography, it can be printed to hard

copy by using the PRINT option or returned to the output by using the OUTPUT option.

PRINT Option

The PRINT option invokes a prompt that asks you for the file number you want printed. When the number is entered and <RETURN> pressed, the corresponding bibliography is printed and the selected output is automatically displayed.

UP And DOWN Option

These commands are used to view the entire list of selected outputs. They will be needed to page through the list when it is longer than one screen.

Important Features

The program was designed to be user friendly, and also to protect the database from user errors. In case of a crash or failure or escape from the program, try to restablish the program by:

1. First try pressing the <ALT> and "S" keys simultaneously to reset the program.

   If this is not successful, then it will be necessary to restart the program by using steps 2 or 3 and the start-up procedure.

2. Press the reset button on the machine.

3. Turn the computer off, then on.

        The hard copies of the annotated bibliographies are in

alphabetical order and are as follows:

File 91
Ader V.
WISCONSIN BIOMASS GASIFIER
WASTE PRODUCTS TO ENERGY FOR INDUSTRY - FARMS - APARTMENTS
Wisconsin Division Of State Energy, Mid-State Technical
Institute

        This report describes the technology, design
construction, economic viability, and energy saving
potential of gasifying biomass. The report is based on
actual tests conducted on a gasifier/engine/generator set
constructed from inexpensive and salvaged parts.

File 83
FEASIBILITY STUDY FOR ALTERNATIVE FUELS PRODUCTION
FLUIDIZED BED GASIFICATION OF RICE HULLS
Department of Energy, American Rice Inc.
DOE File No. DOE/RA/50378

        The study examined the feasibility of constructing an
alternative fuel production facility that used waste rice
hulls. Using a fluidized-bed gasifier to generate low Btu
producer gas showed the most promise.

File 3
Annamalai K., Sweeten J.M., LePori W.A., Parnell C.B., Parke
J.H.
FUEL CHARACTERIZATION AND COMBUSTION STUDIES ON FEEDLOT
MANURE
Texas A&M University   1984

        Ultimate and proximate analyses of manure were carried
out. Manure ash was analyzed for determining the fouling
characteristics. Preliminary thermokinetic data on pyrolysis
of manure was obtained by pyrolyzing manure in TGA and DSC
apparatus. Thermochemical conversion of manure with a small
scale fluidized-bed combustion facility at Texas A&M was
discussed.

File 53
Barrett J.R., Richey C.B.
UTILIZATION OF BIOMASS FOR ENERGY
Purdue University, Agr. Engr. Dept.
Period: 01 Oct. 82 to 30 Sep. 87

    The objectives of this study are to develop the
technology and equipment for using biomass as a renewable
energy source. The study is also being used to design
equipment and determine operational procedures for direct
burning, gasification or pyrolsis of agricultural materials.

File 96
Beck S.R.
ECONOMIC FEASIBILITY OF CATTLE MANURE AS A CHEMICAL
FEEDSTOCK
Texas Tech University, Chemical Engineering Department
Presented at the 4th International Symposium on Livestock
Wastes
April 1980

    Bench scale trials were conducted to study the
gasification of manure. The gas produced from the air blown
gasifier contained mostly nitrogen, carbon dioxide, and
hydrogen. The nitrogen and hydrogen mixture was then used as
chemical feedstock to supply an ammonia plant. The results
and the economics of the study are discussed.

File 80
Beeckmans J.M.
DEVELOPMENT OF A SIMPLE DUAL-BED FLUIDIZED GASIFIER FOR
BIOMASS AND OTHER PYROLYZABLE WASTES.
Natural Sciences and Engineering Research Council (Canada),
University of Western Ontario
Period: Nov. 1981 to Nov. 1984

    The object of the project was to develop a simple
dual-chamber fluidized-bed system for gasifying biomass to
produce a gas having a calorific value in the range of 10-20
MJ/Nm.

File 85
Beierle F.P.
PYRENCO'S EXPERIENCE IN BIOMASS GASIFICATION
Presented at the 7th International FPRS Industrial Wood
Energy Forum, Nashville, Tennesse, Sept. 1983

This paper discusses the catalytic gasification
technology implemented in Pyrenco's research and commercial
fixed bed gasifiers. Applications to the heating of
greenhouses, drying of corn and hops, and cogeneration of
electricity are described.

File 66
Brink D.L.
PYROLYSIS-GASIFICATION OF ORGANIC RESIDUES--FOREST &
AGRICULTURE FOR ENERGY AND PRODUCT RECOVERY
University of California, Forest Products Lab.
Period: 25 Jan. 74 to 30 Sep. 85

The goal of the project was to develop data for design
of processes involving production of energy, isolation of
fuel gases and/or organic chemicals, and/or inorganic
chemicals of value from biomass residual generated in
forestry and agricultural enterprises.

File 62
Buchele W.F., Marley S.J., Smith R.J.
AN INTEGRATED FARM ENERGY SUPPLY FOR THE IOWA FARM
Iowa State University, Agr. Engr. Dept.
Period: 01 Jul. To 30 Jun. 83

The purpose of the research was to develop and promote
the use of portable corncob gasifiers on tractors in an
integrated energy system for the Iowa farm.

File 44
Bunn J.M., Delwiche M.J., Payne F.A.
PROCESSING AND STORAGE OF SOUTHERN AGRICULTURAL COMMODITIES
Clemson University, Agr. Engr. Dept.
Period: 01 Oct. 84 to 30 Sep. 89

The objective of the project is to develop and evaluate
systems that can use alternative energy sources as a
substitute for fossil fuels. The project uses chipped wood
in an updraft gasification-combustion process to produce
energy for drying grain and curing tobacco.

File 82
Chamberland A.
GASIFICATION OF HARVEST RESIDUES FOR THE PRODUCTION OF
ENERGY
Agriculture Canada, Inst. de recherche de l'Hydro-Quebec,
Varennes Quebec, 1980

     The objective of the research was to study the
possibility of using gasification equipment in the farm
sector to supply energy from crop residues for various farm
operations.

File 5
Chang C.C., Fan L.T., Walawender W.P.
DYNAMIC MODELING OF BIOMASS GASIFICATION IN A FLUIDIZED BED
Kansas State University, Dept. Chem. Engr.
AIChE Symposium Series, No.234, Vol. 80

     A model has been developed to describe the dynamic
behavior of a fluidized bed for biomass gasification. The
model takes into account the devolatilization of biomass,
cracking and other reactions of volatiles and char
gasification reactions. Both dynamic behavior and steady-
state performance of the gasifier have been simulated based
on the model developed. The results are compared with
experimental data obtained with feedlot manure in a pilot-
scale, fluidized-bed gasifier under steady-state conditions.

File 48
Clark S.J., Schrock M.D.
ALTERNATE FUELS FOR AGRICULTURAL INTERNAL COMBUSTION ENGINES
Kansas State University, Agr. Engr. Dept.
Period: 01 Jul. 83 to 30 Jun. 85

     The research involves feasibility studies involving
energy crop production costs. The energy utilized to produce
a unit of energy will be determined. Engine performance,
emissions, deposits, and wear tests will be carried out for
various fuels including low grade producer gas.

File 40
Dybing K.B. (M.Sc. Thesis, 1984)
CROP RESIDUE GASIFICATION
Kansas State University, Dept. Chem. Engr.

    Corn and sorghum stover were both gasified in a 0.23m
I.D. fluid bed reactor. The effect of reactor temperature on
the produced gas volumetric yield, composition, and higher
heating value was studied. Also a conceptual design of a
gasifier was used to evaluate the capitol investment,
operating costs, and profitability for a farm scale gasifier
to fuel a irrigation pump and a grain drier.

File 70
ENERGY INTEGRATED FARM SYSTEMS: COGENERATION FEASIBILITY
STUDY
Energy Management Corporation, May 1983
DOE Contract No. DEFC-07-81-cs-40382

    The report summarizes the results of a feasibility
study for application of a Rankine cycle cogeneration system
in conjunction with a biomass gasifier/combustor. The
proposed system is based on a steam cycle using heat
recovered from the exhaust gases of the combustor system.
The system is fueled by cotton gin trash produced by a
cotton ginning operation.

File 25
Energy Resources Co. Inc., Walnut Creek, CA
MOBILE PYROLYSIS UNIT TO CONVERT CALIFORNIA'S AGRICULTURAL
AND FORESTRY WASTE TO CLEAN FUELS
Sept., 1979

    The overall objective of this report is to examine the
technical, economic, and environmental feasibility of a
mobile pyrolysis unit to convert agricultural and forestry
residues to marketable energy forms.

File 55
Eoff K., Huffman J.B., Wang S.C.
THERMOCHEMICAL GASIFICATION OF BIOMASS -- SCREENING
University of Florida, Forest Resources and Conservation
Period: 10 Aug. 81 to 31 Dec. 83

    The goal of the research is to determine the
thermochemical gasification efficiencies of different
biomass feedstocks.

File 21
Eoff K.M., Post D.M.
HOW TO POWER A GASOLINE ENGINE WITH WOOD
Cooperative Extension Service, Univ. of Florida, Inst. of
Food and Agricultural Sciences. 9-15M-80

This paper covers the basic principles of operation for
a downdraft wood gas generator, for producing engine grade
gas.

File 77
GASOGENS
U.S. Department of Agriculture, Forest Products Laboratory
Report No. 1463, 1962

This report discusses the history of gasification and
its general principles, fuels, and equipment.

File 30
Foster G.H., Baker K.D., Barrett J.R., Tuite J.
COMBINATION DRYING WITH RENEWABLE ENERGY
Purdue University
ASAE Paper No. 82-3522

A combination corn drying system using renewable energy
sources for heat was tested in 1981 and 1982. The first
part, high temperature drying phase, used heat from the
gasification of corn cobs. In the second portion of the
combination the drying was completed in the bin using solar
heated air.

File 58
Goss J.R.
GAS PRODUCER RETROFITTED PORTABLE NATURAL GAS ENGINE FARM
IRRIGATION POWER PLANT
University of California, Agr. Engr. Dept.
Period: 01 Jul. 80 to 30 Jun. 85

The object of this research is to develop and test a
system for pumping on-farm irrigation water using crop
residues as a fuel source. A natural gas engine-electric
power plant retrofitted with a gas producer to convert crop
residues into low-Btu gas for the engine fuel will be
designed to deliver about 95% of the rated horsepower.

File 49
Goss J.R.
ENGINEERING SYSTEMS FOR THERMOCHEMICAL CONVERSION OF BIOMASS
University of California, Davis, Agr. Engr. Dept.
Period: 04 Feb. 83 to 30 Sep. 88

The object of the research is to design, develop, and determine performance and operating characteristics of processes for thermochemical conversion of biomass. Systems to process and store feedstocks will be investigated, and operating characteristics of burners and engines will be evaluated.

File 33
Goss J.R., Mehlschau J.J., Jenkins B.M.
DOWNDRAFT GAS PRODUCER SYSTEMS TO UTILIZE CROP AND WOOD RESIDUES
University of California, Davis, Agr. Engr. Dept.
Presented at; 9th International Congress of Agricultural Engineering, July 8-13, 1979

This paper reports on the design, operation, and test results of a portable pilot plant downdraft gas producer. The gasifier was used to fuel a steam boiler, a dual fueled diesel engine-electric generator set and a heated air burner which supplied process heat for crop drying.

File 93
Graham R.G.
PRESENT STATUS OF WOOD PYROLYSIS AND GASIFICATION ACTIVITIES IN CANADA
Forintek Canada Corp., Ottawa Canada
Presented at The Sixth International FPRS Industrial Wood Energy Forum '82, Vol. II of the preceedings

The research, development, and commercial demonstration of Canadian wood pyrolysis and gasification are discussed in detail. This discussion includes process parameters, thermal efficiencies, product yield and quality, product applications, and technical assessment. The Canadian contribution to the state of the art is summarized.

File 81
Grandbois M.A.
PYROLYSIS OF AGRICULTURAL BIOMASS AS A SOURCE OF FUELS FOR
CANADIAN FARM OPERATIONS
Agriculture Canada, Sandwell Beak Research Group,
Mississauga Ont.
Nov. 1980

     The objective of the research was to assess whether
pyrolysis of agricultural residues is a feasible process for
fuel production on the farm. The tasks included a literature
review, determination of feedstock characteristics,
pyrolysis of corn stover and oat straw, and an assessment of
end-use applications of the fuels obtained.

File 63
Gunkel W.W.
AGRICULTURAL AND FOREST WASTE PRODUCTS AS AN ENERGY SOURCE
Cornell University, Agr. Engr. Dept.
Period: 05 Oct. 82 to 30 Sep. 85

     The objectives of this study are to determine the
feasibility of using terpenes as a fuel for diesel and
gasoline engines and to design, construct, and test an
improved producer gas system for burning lignin and other
agricultural and forest waste products.

File 74
Hargrave R.H.
FIELD TESTING SMALL GASIFIER FILTER SYSTEMS
Rocky Creek Farm Gasogens Inc., LaCrosse Florida
Presented at the 16th Biomass Thermochemical Conversion
Contractor's Meeting, 1984
DOE File No. CONF-8405157/PNL-SA-12403

     Discusses research on the testing of existing filter
systems and the development of improved gas cleaning
systems. The study covers both stationary and mobile
gasifiers. The field testing will be carried out on a
variety of typical agricultural operations.

File 65
Hills D.J., Dobie J.B., Goss J.R.
UTILIZATION OF ANIMAL, CROP AND PROCESSING RESIDUES
University of California, Agr. Engr. Dept.
Period: 25 Mar. 75 to 30 Sep. 86

     One of the project's objectives is to increase
utilization of crop residues through pyrolysis/gasification.

File 100
Hodam R.H., Williams R.O.
ELECTRICITY GENERATION VIA BIOMASS GASIFICATION
AT SIZES FROM 10 kWe TO 1000 kWe
Hodam and Associates, Sacramento, California
Presented at The Sixth International FPRS Industrial Wood Energy
Forum '82, Vol. II of the proceedings

The paper discusses the use of low BTU producer gas to fuel reciprocating internal combustion engine/generator sets. The report describes three systems that can be used to supply electricity and evaluates their economics. The examples described are 10, 100, and 1000 kWe systems.

File 84
Horsfield B.
CURRENT EUROPEAN ACTIVITIES IN GASIFICATION
University of California, Agr. Engr. Dept., 1983

Current European activities in gasification are discussed with particular references to the programs in England, France, and Sweden. In England research is underway by several firms to develop an extremely low cost method for converting crop residues into electrical power. Both France and Sweden are investgating the use of producer gas in dual-fueled diesel engines.

File 34
Horsfield B., Williams R.O.
ENERGY FOR AGRICULTURE AND THE GASIFICATION OF CROP RESIDUES
University of California, Davis, Agr. Engr. Dept., 1978

The theory of gasification is reviewed and its historical application to crop residue is presented. Several potential applications are discussed, including heating, fuel for internal combustion engines, crop drying, irrigation pumping, and processing energy.

File 32
Horsfield B., Doster H., Peart R.
DRYING ENERGY FROM CORN COBS: A TOTAL SYSTEM
University of California, Davis, Agr. Engr. Dept.
Presented at the Conference on Energy and Agriculture,
Washington Univ., June 16-19, 1976

    The paper discusses the feasibility of using corn cob
gasification to supply the energy for crop drying. The study
includes the authors views on both system efficiency and
economics.

File 23
Horsfield B., Williams R.O.
TECHNOLOGICAL AND ECONOMIC ASSESSMENT OF THE UTILIZATION OF
RICE STRAW RESIDUE FROM THE SACRAMENTO VALLEY FOR ON FARM
POWER GENERATION
University of California, Davis, Agr. Engr. Dept.
August, 1976

    This report examines alternative uses for rice straw in
order to provide on-farm energy. Conversion processes are
also discussed with a major emphasis placed on gasification.

File 14
Hoveland D.A., Walawender W.P., Fan L.T.
STEAM GASIFICATION OF PURE CELLULOSE.
2. ELEVATED FREEBOARD TEMPERATURE
Kansas State University, Dept. Chem. Engr.
Ind. Eng. Chem. Process Des. Dev. 1985, 24, 818-821

    Alpha-cellulose was gasified with steam in a fluidized-
bed reactor to determine the effects of elevated free board
temperatures on the gasifier performance. The results showed
that the gas yield, energy recovery. and carbon conversion
followed the same trends obtained with no temperature
elevation.

File 10
Hoveland D.A., Walawender W.P., Fan L.T., Lai F.S.
STEAM GASIFICATION OF GRAIN DUST IN FLUIDIZED BED REACTOR
Kansas State University, Dept. Chem. Engr.
ASAE TRANSACTIONS 1982

    Corn dust was gasified with steam in a 5 cm (2 in.)
I.D. bench scale fluid-bed reactor. Experiments were
conducted over a wide temperature range to examine the
influence of temperature on the gas composition, yield,
heating value, and energy recovery.

File 26
Jenkins B.M., Arthur J.F., Miller G.E., Parsons P.S.
LOGISTICS AND ECONOMICS OF BIOMASS UTILIZATION
University of California, Davis
ASAE Paper No. 83-3020

Technical and economic comparisons were made of systems
for collecting, processing, storing, and transporting rice,
wheat, and barley straw, corn and sorghum stover, cotton
stalks, orchard prunings, and forest slash. Costs of
producing electricity, syngas, and synthetic natural gas
from biomass were computed.

File 86
Kaupp A., Goss J.R.
STATE OF THE ART FOR SMALL SCALE (2-50 KW) GAS
PRODUCER-ENGINE SYSTEMS
U.S. Department of Agriculture, Forest Service; Univ. of
Calif.

Reported are the results of an extensive literature
search regarding past and present research and commercial
applications of small gasification systems. Discussions
include the thermochemistry of gasification, fuel
preparation, conditioning of the resulting producer gas and
its use for operating internal combustion engines. The
technical feasibility and future developmental
considerations of a simple, efficient gasifier design are
investigated in detail.

File 52
Keener H.M., Henry J.E., Anderson R.J.
FARMSTEAD ENERGY FROM BIOMASS - THERMAL AND ELECTRICAL
Ohio State University, Agr. Engr. Dept.
Period: 01 Oct. 82 to 30 Sep. 85

The objectives of the research are to identify
plentiful sources of biomass that are adaptable to the
fluidized-bed combustion process, further develop and refine
fluidized-bed combustion system for use with biomass other
than corncobs, and to develop an electrical generation
system which uses biomass as a source of power in a
cogeneration process.

File 51
Keener H.M., Anderson R.J., Henry J.E.
A FARMSTEAD ENERGY CENTER: BASED UPON CORNCOB COMBUSTION AND
COGENERATION
Ohio State University, Agr. Engr. Dept.
Period: 15 Sep. 82 to 30 Jun. 85

The goal of the research is to develop specifications
for a hot gas turbine to be coupled to a fluidized-bed
corncob combustor and outline the possible avenues for the
energy use on the farm.

File 29
Kutz L.J., Barrett J.R., Richey C.B., Jacko R.B.
DOWNDRAFT CHANNEL GASIFIER OPERATION AND PARTICULATE
EMISSIONS
Purdue University
ASAE Paper No. 82-3096

A single channel downdraft gasifier has been designed,
constructed, and parametrically tested using corncobs at
three moisture contents. Primary airflows, gasification
rates, temperatures, particulate emissions, and operational
characteristics are presented.

File 1
LePori W.A., Parnell C.B., Carney D.B., Ling Peter P.
SMALL SCALE POWER GENERATION FROM BIOMASS-TECHNICAL
POTENTIAL
Texas A&M University
ASAE Paper No. 83-3541

The object of this paper is to present results of
research using fluidized-bed thermal conversion technology
and discuss their implications in relation to the technical
feasibility of small-scale power generation. The components
of the system, gasifier, filtering system, boiler, and steam
turbine are analyzed.

File 39
LePori W.A., Parnell C.B., Lacewell R.D., Pollock T.C.
ON-SITE ENERGY PRODUCTION FROM AGRICULTURAL RESIDUES
Texas A&M University
Report for Texas Energy and Natural Resources Advisory
Council
Project 79-8-1-5C-2; Microfiche No. TENRAC/EDF-108

This paper evaluates fluidized-bed energy technology
for converting agricultural residues into usable energy
forms. It also covers an economic analysis of the use of
gasification on the farm and a site specific analysis.

File 54
Lee H.H., Huffman J., Eoff K.
ADVANCEMENT OF THERMO-CHEMICAL GASIFICATION OF BIOMASS TO
METHANE
University of Florida, Forest Resources and Conservation
Period: 22 Jul. 81 to 31 Dec. 82

The goal of the research is to develop fundamental
information required to produce methane from biomass in the
most economical way by determining reaction conditions, and
process, kinetics and by controlling physical/chemical
parameters.

File 60
Lindley J.A., Roehl L.J., Johnson R.G.
BIOMASS UTILIZATION AS AN ENERGY SOURCE
North Dakota State University, Agr. Engr. Dept.
Period: 01 Sep. 79 to 30 Sep. 84

The objective of the research is to evaluate systems
for collecting, densifying, direct combustion, and
gasification of biomass. The evaluation is used to determine
the economic feasibility for gasification on the farm.

File 94
Lindman N.G.
PRESENT STATUS OF GASIFIERS IN EUROPE
The Royal Institute of Technology, Department of Chemical
Technology, Stockholm, Sweden
Presented at The Sixth International FPRS Industrial Wood
Energy
Forum '82, Vol. II of the proceedings

The motive and prospects for the development of biomass
gasifiers in Western Europe are discussed. Some commercial
as well as developing gasification processes are presented

and discussed from a technical point of view. Some research
activities are also presented.

File 50
Loewer O.J., Taraba J.L., White G.M.
PARTICULATE DEPOSITION WHEN PASSING GASIFICATION-COMBUSTION
GASES THROUGH GRAIN
University of Kentucky, Agr. Engr. Dept.
Period: 01 Sep. 82 to 31 Aug. 85

        The overall goal is to determine if passing biomass
gasification-combustion gases directly through grain during
drying will contaminate the grain so as to present a health
hazard.

File 98
Maniatis K., Schoeters J., Buekens A.
BIOMASS GASIFICATION IN A FLUIDIZED BED REACTOR
Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel
Presented at The Sixth International FPRS Industrial Wood
Energy
Forum '82, Vol. II of the proceedings

        This paper presents partial results obtained in the
course of a comprehensive R & D program to study downdraft
moving-bed and fluidized-bed gasifiers. The main purpose of
the program was to obtain information on the efficiencies of
the gasifiers and their operating limits. The influence of
different operating parameters such as air stream and
feedstock flowrates as well as bed and freeboard heating on
the performance of the gasifiers were examined. The use of
agricultural feedstocks is discussed.

File 79
Mayer E.
DEVELOPMENT AND EVALUATION OF A SMALL SCALE GASIFIER SYSTEM
FOR UTILIZING FARM WASTES
Agriculture Canada, Mayer and Poer Corp. Inc., Winnipeg
Manitoba
Period: Nov. 1983 to Nov. 1984

        The object of the research was to optimize the
operation and monitor the performance of a prototype
gasifier using locally available fuels: cubed wood wastes,
flax straw, sunflower hulls, and corn stalks. The use of the
producer gas will be evaluated in direct-fired systems such
as boilers and grain drying systems.

File 31
McCoy E.S., Barrett J.R., Richey C.B.
ANALYSIS OF MASS AND ENERGY TRANSFERS IN A BIOMASS
GASIFIER/COMBUSTOR FURNACE
Purdue University, Agr. Engr. Dept.
ASAE Paper No. 81-3017

A computerized procedure is described which uses real
data and analyzes the mass and energy transfers through a
two-stage biomass gasifier/combustor furnace. The
sensitivity of the analysis program to perturbations in the
input data is discussed.

File 99
Moreno F.E.
BIOMASS GASIFICATION/GAS TURBINE COGENERATION SYSTEM
Advanced Energy Applications Inc., Los Altos California
Presented at The Sixth International FPRS Industrial Wood
Energy
Forum '82, Vol. II of the proceedings

Various gasification/gas turbine cogeneration systems
are discussed. Their advantages and disadvantages are
examined from an equipment and economic point of view.
Factors influencing the design and behavior of the
gasifier/gas turbine system are viewed and the results of
experiments briefly discussed.

File 64
Morey R.V., Gustafson R.J., Schertz C.E.
REDUCTION OF NON-RENEWABLE ENERGY CONSUMPTION FOR GRAIN
DRYING
University of Minnesota, Agr. Engr. Dept.
Period: 01 Jul. 75 To 30 sep. 86

The object of the research is to develop engineering
data on drying characteristics of corn and sunflowers, and
to develop management recommendations for corn drying.
Performance data on the gasification of various feedstocks
is also to be determined.

File 78
North Carolina Alternative Energy Corp.
AGRICULTURE WOOD GASIFICATION/COGENERATION PROJECT
North Carolina State University, Dept. Agriculture, 1985

The project covers a study of possible biomass
cogeneration systems for use by farmers. The current status
of the project includes the fabrication of a fixed-bed
downdraft wood gasifier coupled with a 55 kw
engine/generator.

File 90
PRODUCER GAS: ANOTHER FUEL FOR MOTOR TRANSPORT
National Research Council
National Academy Press, Washington D.C., 1983

The purpose of this publication is to introduce
producer gas to researchers, agencies, and institutions
engaged in assisting developing countries. The report
discusses history, technology, fuels, economics, stationary
and large scale use, and future research needs of
gasification.

File 20
Ogunlowo A.S., Chancellor W.J., Goss J.R.
DUAL-FUELING A SMALL DIESEL ENGINE WITH PRODUCER GAS
University of California,Davis, Agr. Engr. Dept.
ASAE Transactions 1981

A single cylinder, air cooled diesel engine was fueled
with producer gas carbureted into the intake air. This
mixture was then ignited by injection of pilot amounts of
diesel fuel. The producer gas was obtained by gasifying wood
chips.

File 102
Edited by; Overend R.P., Milne T.A., Mudge L.K.
FUNDAMENTALS OF THERMOCHEMICAL BIOMASS CONVERSION
Book; Published by Elsevier Applied Science Publishers
(1985)
52 Vanderbilt Ave. New York, NY 10017

This book reports on the up-to-date fundamentals of
thermochemical conversion of biomass. The book was edited
through the cooperation of both the United States and
Canadian governments.

File 7
Parke P.P., Clark S.J., Walawender W.P.
BIOMASS PRODUCER GAS FUELING OF INTERNAL COMBUSTION ENGINES
Kansas State University
Presented at Energy From Biomass and Wastes V; Jan. 26-30,
1981
Sponsored by Institute of Gas Technology

     Results are presented for spark ignition engine
performance characteristics. The engine was fueled with
biomass producer gas, obtained from corn stover gasified in
a fluidized bed.

File 59
Parker B.F., Loewer O.J., Dougherty C.T.
PROCESSING AND STORAGE OF SOUTHERN AGRICULTURAL COMMODITIES
University of Kentucky, Agr. Engr. Dept.
Period: 01 Oct. 84 to 30 Sep. 89

     One goal of the research is to develop and evaluate
systems to use alternative energy sources to substitute for
fossil fuels. This includes the study of a biomass
gasification-combustion system using different feedstocks.

File 56
Payne F.A., Albhin J.G., Bunn J.M.
DESIGN OF A CORD WOOD GASIFICATION & GAS COMBUSTION SYSTEM
FOR CURING TOBACCO
Clemson University, Agr. Engr. Dept.
Period: 01 Jul. 81 to 30 Jun. 85

     The purpose of this research is to develop a cord wood
combustion system to provide thermal energy for multiple
farm applications but especially for curing tobacco. The
system is to consist of a updraft gasifier, closed coupled
to combustion module. The system's parameters are to be
determined for the application of controls and the sizing
for different farm applications.

File 45
Payne F.A., Chandra P.K., Dunlap J.L.
EVALUATING RECENTLY DEVELOPED TWO-STAGE COMBUSTION
TECHNOLOGY
Clemson University, Agr. Engr. Dept.
Period: 01 Sep. 84 to 31 Aug. 85

The object of this research is to investigate recent
developments in gasifier, combustor and control design which
may potentially simplify two-staged combustor design for
small scale applications. The small scale applications
considered in the study include crop drying.

File 28
Payne F.A., Alphin J.G.
EXHAUST GAS RECIRCULATION FOR CONTROL OF UPDRAFT GASIFIER
GRATE TEMPERATURE
Clemson University, Ag. Engr. Dept.
ASAE Paper No. 83-3072

Exhaust gas recirculation was tested and shown to
effectively reduce grate temperatures for updraft
gasification of wood chips and to have no significant effect
on system efficiency.

File 42
Payne F.A., Alphin J.G., Bunn J.M.
A CORD WOOD GASIFICATION AND GAS COMBUSTION SYSTEM
Clemson University, Agr. Engr. Dept.
ASAE Paper No. 81-3589

A cord wood gasifier combustor was designed and tested.
The gas produced was used to heat water for an on-the-farm
tobacco curing operation.

File 41
Payne F.A., Ross I.J., Walker J.N., Brashear R.S.
GASIFICATION-COMBUSTION OF CORNCOBS AND ANALYSIS OF EXHAUST
University of Kentucky, Agr. Engr. Dept.
ASAE Paper No. 80-3025

A gasification-combustion process for converting corn
cobs into thermal energy was tested to determine its
operational characteristics, and measure the quality of the
exhaust from the system. Based on the test results, the
quality of the exhaust appeared sufficiently clean for
drying grain.

File 35
Payne F.A., Ross J.N., Walker J.N.
FORCED FED BIOMASS GASIFICATION COMBUSTION FOR DRYING GRAIN
University of Kentucky, Agr. Engr. Dept.
ASAE Paper No. 79-4546

    The design for a gasification-combustion process was
reviewed. This design has been used for a 200 KJ/sec
experimental burner for burning corn cobs, fodder, and
grain. The drying potential of biomass using the exhaust-air
mixture directly for drying is discussed.

File 57
Peart R.M.
ENERGY EFFICIENCY IN AGRICULTURAL BIOMASS PRODUCTION AND
PROCESSING
Purdue University, Agr. Engr. Dept.
Period: 07 May 81 to 30 Sep. 85

    The goal of this research is to develop systems and
procedures for integrating the use of crop by-products into
conventional crop production systems. The main area of
investigation is the modeling and simulation of grain drying
utilizing biomass gasification.

File 68
Peart R.M., Richey C.B.
EQUIPMENT FOR ENERGY CONVERSION
Purdue University, Agr. Engr. Dept.
Period: 22 Feb. 80 to 21 Feb. 84

    The goal of the investigation was to study the
thermochemical conversion of biomass, including corn cobs,
corn stover, and other agricultural crop residues into
combustible producer gas and/or heat.

File 17
Raman P., Walawender W.P., Fan L.T., Chang C.C.
MATHEMATICAL MODEL FOR THE FLUID-BED GASIFICATION OF BIOMASS
MATERIALS. APPLICATION TO FEEDLOT MANURE
Kansas State University, Dept. Chem. Engr.
I&EC Process Design & Development, 1981, 20, 686.

    A mathematical model was developed to describe the
gasification of biomass in a fluid bed reactor. The model
was applied to the gasification of feedlot manure and used
to compute gas composition and yields of gas, liquid, and
solid products.

File 16
Raman P., Walawender W.P., Fan L.T., Howell J.A.
THERMOGRAVIMETRIC ANALYSIS OF BIOMASS.
DEVOLATILIZATION STUDIES ON FEEDLOT MANURE
Kansas State University, Dept. Chem. Engr.
I&EC Process Design & Development, 1981, 20, 630.

The devolatilization reactions of feedlot manure were studied by means of a thermogravimetric analyzer. The effects of size fraction, heating rate, and purge gas rate on the thermogram characteristics, such as the total weight percent devolatilized and the temperature at which the maximum rate of weight loss occurred, were analyzed statistically.

File 11
Raman K.P., Walawender W.P., Shimizu Y., Fan L.T.
GASIFICATION OF CORN STOVER IN A FLUIDIZED BED
Kansas State University, Dept. Chem. Engr.   1980

Dried corn stover, after being run through a hammer mill, was gasified in a series of test runs at 840 to 1020 K in a 22.9 cm I.D. fluid-bed gasifier. The bulk of the bed was composed of silica sand and was fluidized with a mixed gas composed of steam, nitrogen, and carbon dioxide. This work reports on the effect of temperature on the yield, composition, and heating value of the produced gas.

File 8
Raman K.P., Walawender W.P., Fan L.T.
GASIFICATION OF FEEDLOT MANURE IN A FLUIDIZED BED REACTOR.
THE EFFECT OF TEMPERATURE
Kansas State University, Dept. Chem. Engr.
I&EC Process Design & Development; 1980, 10, 623

Dried feedlot manure was gasified in a 22.9 cm I.D. fluidized-bed reactor. The effect of reactor temperature on the yield, composition, and heating value of the produced gas and also on the energy recovery of the process was studied. The results were compared with those predicted by thermochemical calculations.

File 61
Rask N., Hitzhusen F.
ENERGY POLICY, BIOMASS, AND AGRICULTURE: AN ECONOMIC
ANALYSIS
Ohio Agr. R & D Center, Agr. Economics and Rural Sociol
Period: 08 Mar. 79 to 30 Sep. 85

The objectives of the research are to determine the
impact of present and evolving energy policies on
agriculture, analyze the economics of selected crop biomass
options, and delineate the role of agriculture in future
energy strategies.

File 92
Reed T.B.
PRESENT STATUS OF GASIFICATION/PYROLYSIS
PROCESSES IN THE UNITED STATES
Solar Energy Research Institute
Presented at The Sixth International FPRS Industrial Wood
Energy Forum '82, Vol. II of the proceedings

The report discusses both the history and state of the
art technology of gasification in the United States. Also
the criteria for gasifier selection and the standards for a
gasifier are reported.

File 88
Reed T.B.
BIOMASS GASIFICATION: PRINCIPLES AND TECHNOLOGY
Noyes Data Corp., 1981
Energy Technology Review No.67, Park Ridge N.J.

This text represents a survey of the technical
background of biomass gasification, the status of present
research being conducted, and recommendations for future
research and development.

File 87
Reed T.G.
GENERATOR GAS: THE SWEDISH EXPERIENCE FROM 1939-1945
Solar Energy Research Institute, Golden Colorado
Report No. SERI/SP-33-140, 1979

Technical and commercial development of gas generators
in Sweden during and prior to World War II is described.
Details on reactor designs, operating characteristics, fuel
preparation problems, etc. are provided.

File 76
Reed T.B., Jantzen D.E.
DIRECTORY OF AIR BIOMASS GASIFIERS IN THE U.S. AND CANADA
Solar Energy Research Institute, 1979

This directory lists the addresses, their, product and some general information about various companies designing and manufacturing air biomass gasifiers.

File 27
Richey C.B., Barrett J.R.
AUTOMATIC CORNCOB FEEDING INTO A GASIFIER FURNACE
Purdue University, Agr. Engr. Dept.
ASAE Paper   No. 83-3071

An automatic corncob feeding system, including level sensor, airlock feeder, and flow meter, is described. This system was designed, constructed, and tested on a pressurized downdraft gasifier.

File 38
Richey C.B., Barrett J.R., Foster G.H.
BIOMASS CHANNEL-GASIFICATION FURNACE
Purdue University, Agr. Engr. Dept.
ASAE Transactions. Vol. 25, No. 1, pp. 2-6, 1982

A new concept in channel gasification, to supply heat energy on the farm, was investigated by means of a small exploratory module. Initial tests were made using corn cobs as fuel with the exhaust used as heat for direct grain drying. The results of the tests were found to be promising.

File 43
Richey C.B., Barrett J.R., Foster G.H., Kutz L.J.
BIOMASS DOWNDRAFT-CHANNEL GASIFIER-FURNACE FOR DRYING CORN
Purdue University, Agr. Engr. Dept.
ASAE Paper No. 81-3590

A cross-draft channel gasification concept was modified for downdraft action to obtain a hotter and cleaner burning gas to dry corn. The results of the modification and the drying tests were discussed.

File 67
Ross I.J., Parker B.F., Butler J.L.
INTEGRATED MULTIPLE-USE SOLAR SYSTEM WITH BIOMASS
GASIFICATION COMBUSTION BACKUP
University of Kentucky, Agr. Engr. Dept.
Period: 01 Oct. 80 To 14 Sep. 85

The purpose of the project was to develop an
integrated, multiple, use system to heat air for animal
housing and for grain drying, using solar thermal and
biomass gasification as energy sources with a rock-bed heat
storage.

File 101
Russell B.
BIOMASS GASIFICATION FOR INTERNAL COMBUSTION ENGINES
IN EUROPE AND THE UNITED STATES
ECON (Energy Conversion Co.), Alexander City, Alabama, 1980
In FPRS publication Energy Generation & Cogeneration From
Wood

This paper gives a brief history of biomass
gasification for internal combustion engines and describes
present efforts and developments. A list of the advantages
and disadvantages of a gasification/vehicle system is also
presented.

File 75
Savage G.M.
RESEARCH AND DEVELOPMENT ON BIOMASS GASIFIER/ENGINE SYSTEMS
Cal Recovery Systems Inc., Richmond, California
Presented at 16th Biomass Thermochemical Conversion
Contractor's Meeting , 1984
DOE File No. CONF-8405157/PNL-SA-12403

Cal recovery Systems Inc. is conducting basic research
and development on improving the operation and performance
of biomass gasifier/engine systems. The main part of the
research is to identify areas wherein improvements can be
realized in terms of technical design and overall economics
of system operation.

File 71
Schiefelbein G.F.
BIOMASS GASIFICATION RESEARCH: RECENT RESULTS AND FUTURE
TRENDS
U.S. Department of Energy, Battelle Pacific North-West
Laboratory
Report No. PNL-SA-12841, Feb. 1985

This paper briefly reviews recent research results on
the gasification of biomass and the prospects for commercial
application of these results. Particular emphasis is placed
on current DOE sponsored research involving various methods
of gasification and the effects of different operating
parameters.

File 72
Schiefelbein G.F., Stevens D.J., Gerber M.A.
BIOMASS THERMOCHEMICAL CONVERSION PROGRAM: 1984 ANNUAL
REPORT
U.S. Department of Energy, Battelle Pacific Northwest
Laboratory
Report No. PNL-5442/UC-61D, Jan. 1985

The objective of the Biomass Thermochemical Conversion
Program is to generate scientific data and conversion
process information that will lead to establishment of cost-
effective processes for converting biomass resources into
clean fuels. The research activities described in detail in
this report include: gasification, liquid fuels, and direct
combustion technologies.

File 103
Schulze Lammers P.
INVESTIGATIONS AT A COUNTERCONCURRENT GAS-GENERATOR
WITH STRAW AS A FUEL
Presented at the 41st International Meeting of Agriculture
Tech. Braunscheig, F.R. Germany, Nov. 1983
DOE File No. CONF-8311193

The conversion of biomass energy to electric energy is
investigated in a system using an updraft gasifier coupled
with an internal combustion engine. Straw was one of the
main feedstocks tested.

File 18
Shaw L.N., Post D.M., Eoff K.M.
SELF-CONTAINED BIOMASS ENERGIZED CROP DRIER
Florida Agricultural Experiment Station
ASAE Transactions Vol. 1, No. 1, pp 10-12, 1985

    A crop drier energized with wood chips was designed,
fabricated, and evaluated. An internal combustion engine
fueled from a downdraft gas producer drives the blower, and
waste heat from the engine and gas production system heats
the air.

File 47
Shaw L.N.
SUBSTITUTION OF PRODUCER GAS FOR FOSSIL FUEL IN CITRUS CROP
PRODUCTION
University of Florida, Agr. Engr. Dept.
Period: 15 Feb. 84 to 31 Dec. 86

    The objectives of this project are to develop methods
for citrus tree biomass utilization in gas producers for
fueling internal combustion engines to power irrigation
pumps and other stationary operations. Tests were also run
to develop and test supercharging, after cooling, and other
techniques to return engine performance to petroleum fuel
levels.

File 73
Shaw L.N., Post D.M.
PERFORMANCE ENHANCEMENT OF ENGINES FUELED WITH PRODUCER GAS
University of Florida
Presented at the 16th Biomass Thermochemical Conversion
Contractor's Meeting, 1984
DOE File No. CONF-8405157/PNL-SA-12403

    This paper discusses research that is underway to
develop methods for maintaining power output of spark
ignition and diesel engines fueled with producer gas and to
reduce the attention required for operation. The two methods
under research are the use of turbocharging and the
utilization of a microcomputer to regulate the air-fuel
ratio.

File 19
Shaw L.N., Post D.M., Arnold C.E.
GREENHOUSE HEATING WITH A WOOD GASIFIER FURNACE
University of Florida, Agr. Engr. Dept.
Proc. Fla. State Hort. Soc. 95:158-159. 1982

A wood fueled, gasified furnace has been evaluated for heating a greenhouse in north Florida. This unit heats water that is stored in a large insulated tank located under the middle bench in the house. The hot water is circulated throughout the house heating system as needed. The performance of the system is reported.

File 37
Srivastava A.K., Posselius J.H.
DIMENSIONAL ANALYSIS AND SIMILITUDE MODELING OF THE GASIFICATION PROCESS
Michigan State University, Agr. Engr. Dept.
ASAE Paper No. 81-3588

This paper investigates the feasibility of applying dimensional analysis and similitude modeling to develop scaling laws for the design of a producer gas generator using biomass as a feedstock.

FILE 69
Stanley N.E., Wheeler L.R., Carpenter R.W.
BIOMASS ALTERNATIVE FUELS PROGRAM: FINAL REPORT
EG&G Idaho Inc.
DOE/ID-10113, 1983

This report presents the results of the Biomass Alternative Fuels Program and a review of the individual feasibility studies commissioned by the U.S. Department of Energy. The object of the feasibility studies was to provide comprehensive data to aid potential developers to proceed with the implementation of commercial plants.

File 4
Sweeten J.M., Annamalai K., LePori W.A., Parnell C.B.,
Korenberg J.
COMBUSTION OF CATTLE FEEDLOT MANURE FOR ENERGY PRODUCTION
Texas A&M University
ASAE Paper No. 84-3078

This paper describes the potential of manure for energy
and the results of the thermochemical conversion process
studies using a fluidized bed. The analysis of ash and
emissions from the combustion tests to determine combustion
efficiency are also described in detail.

File 2
Sweeten J.M., Reddell D.L., Stewart B.R.
FEEDLOT MANURE AS AN ENERGY SOURCE
Texas A&M University, Agricultural Engineering Dept.
ASAE Paper No. - (1974)

A comparison was made of the energy savings
available from feedlot manure utilized for the following
purposes: fertilizer, a roughage substitute in feedlot
rations, fuel, and a substitute for natural gas in anhydrous
ammonia production.

File 13
Walawender W.P., Hoveland D.A., Fan L.T.
STEAM GASIFICATION OF PURE CELLULOSE.
1. UNIFORM TEMPERATURE PROFILE
Kansas State University, Dept. Chem. Engr.
Ind. Eng. Chem. Process Des. Dev. 1985, 24, 813-817

Alpha-cellulose was steam gasified in a 5 cm I.D. bench
scale fluidized-bed reactor over a temperature range of 865
to 1060 K. The object of the study was to generate datum
lines for the gas composition, yield, heating value, energy
recovery, and carbon conversion under well defined
conditions.

File 46
Walawender W.P., Fan L.T.
THERMOCHEMICAL PROCESSING OF WOODY AND AGRICULTURAL BIOMASS
Kansas State University, Chem. Engr. Dept.
Period: 01 Jul. 84 to 30 Jun. 87

    One objective of this project was to develop the
relationships between biomass properties and to identify key
properties affecting pyrolysis and gasification. Another
objective was to develop a model for the downdraft gasifier
and to predict possible performance.

File 12
Walawender W.P., Dybing K., Fan L.T.
GASIFICATION OF CORN AND SORGHUM STOVERS IN A FLUIDIZED BED
REACTOR
Kansas State University, Dept. Chem. Engr.
Presented at the IGT Symposium, Energy from Biomass and
Wastes IX,
1985

    Corn stover and sorghum stover were gasified in a
fluidized-bed reactor over various temperatures. The gas
yield, energy recovery, carbon conversion, and gas heating
values for both feedstocks over the various temperatures
were reported.

File 15
Walawender W.P., Hoveland D.A., Fan L.T.
STEAM GASIFICATION OF ALPHA CELLULOSE IN A FLUID BED REACTOR
Kansas State University, Dept. Chem. Engr.
Text: Fundamentals of Thermochemical Biomass Conversion
Elsevier Applied Science Publishers, New York, 1985

    Alpha cellulose was gasified in a fluidized-bed reactor
with steam. The temperature of the reactor was varied in
order to correlate relationships between temperature and gas
yield, gas composition, energy recovery, and carbon
conversion.

File 97
Walawender W.P., Hoveland D.A., Arfwidsson D., Fan L.T.
STEAM GASIFICATION OF WHEAT STRAW IN A FLUIDIZED BED
Kansas State University, Dept. Chem. Engr.
Presented at The Sixth International FPRS Industrial Wood
Energy Forum '82, Vol. of the proceedings

    Wheat straw was gasified with steam in a fluidized-bed
reactor over a range of temperatures at atmospheric
pressure. Correlations were made between temperature and
volumetric gas yields, heating values, mass fraction
distribution, and energy recovery. The procedures and the
results of the tests are discussed in detail.

File 6
Walawender W.P., Ganesan S., Fan L.T.
STEAM GASIFICATION OF MANURE IN A FLUIDIZED BED
INFLUENCE OF LIMESTONE AS A BED ADDITIVE
Kansas State University, Dept. Chem. Engr.   1981

    Dried feedlot manure was gasified with steam in a 5 cm
(2 in.) I.D. bench scale fluid-bed reactor. The bulk of the
bed was composed of a matrix of silica sand and steam was
used as the sole fluidizing gas. It was observed that the
addition of limestone to the silica matrix could prevent the
formation of solid agglomerates and subsequent choking of
the bed. Experiments were conducted both with and without
the limestone additive, and the influence of temperature on
the gas composition, yield, and heating value were examined.

File 9
Walawender W.P., Raman K.P., Fan L.T.
GASIFICATION OF CARBONACEOUS MATERIALS IN A FLUIDIZED BED
REACTOR
Kansas State University, Dept. of Chem. Engr.
Presented at Bio-Energy '80, World Congress and Exposition

    A pilot-scale fluid bed gasifier (22 cm I.D.) was used
to pyrolyze several carbonaceous materials, including
manure. Gasification was conducted over various temperatures
and fluidizing gas velocities. The volume of producer gas
and its heating value were then correlated to the
temperature.

File 36
Williams R.O., Goss J.R.
AN ASSESSMENT OF THE GASIFICATION CHARACTERISTICS OF SOME
AGRICULTURAL AND FORESTRY INDUSTRY RESIDUES USING A
LABORATORY GASIFIER
University of California, Davis, Agr. Engr. Dept.
Resource Recovery and Conservation, 3 (1979) 317-329

A laboratory scale downdraft gasifier was used to study
the gasification properties of certain biomass fuels. The
biomass fuels tested included rice hulls, cotton gin trash,
wood chips, walnut shells, and corn cobs.

File 24
Williams R.O., Goss J.R., et al
DEVELOPMENT OF PILOT PLANT GASIFICATION SYSTEMS FOR THE
CONVERSION OF CROP AND WOOD RESIDUES TO THERMAL AND
ELECTRICAL ENERGY
University of California, Davis, Agr. Engr. Dept., 1978
ACS Symposium Series, No. 76

The paper describes the development and test results of
a mobile pilot plant to gasify crop and wood residues. The
producer gas is used to dual fuel a modified diesel engine
to produce electrical power. The heat lost through gas
cleanup and engine combustion is recovered and steam is
generated for on-site use.

File 89
Williams R.O.
DEVELOPMENT OF PILOT PLANT GASIFICATION SYSTEMS FOR THE
CONVERSION OF CROP AND WOOD RESIDUES TO THERMAL AND
ELECTRICAL ENERGY
University of California, Dept. Agr. Engr., 1978
American Chemical Society, ACS Symposium Series 76, pp.142-
162

Gasification research was conducted using a down-draft,
moving, packed bed, vertical flow gasifier. Gasifier design
and specific applications and cost projections are
presented.

File 22
Williams R.O., Horsfield B.
GENERATION OF LOW-BTU FUEL GAS FROM AGRICULTURAL RESIDUES
AND EXPERIMENTS WITH A LABORATORY SCALE GAS PRODUCER
9th Annual Conference on Food, Fertilizer, and Agricultural
Residues, Cornell University, April 1977

This paper covers the design, construction, and
operation of a small downdraft gas generator. Farm residues
such as rice hulls, cotton gin trash. wood chips, walnut
shells, and corn cobs are used as fuels.

File 95
Yang V.
PRESENT STATUS AND THE POTENTIAL OF PYROLYSIS/GASIFICATION
SYSTEMS FOR BIOMASS IN THE THIRD WORLD
CTP - Centro de Tecnologia Promon, Rio de Janeiro, Brazil
Presented at The Sixth International FPRS Industrial Wood
Energy
Forum '82, Vol. II of the preceedings

The importance of biomass and the role of pyrolysis/
gasification processes and products for third world
development is analyzed. The history and status of biomass
energy programs in Brazil is reviewed.

Summary of Information

The established information base to date contains 103

bibliographies. The information contained in the database

covers the whole subject area of the gasification of

agricultural residues. Included is information on:

    A. Heating values

    B. Conversion efficiencies

    C. Emissions

    D. Economic feasibilities of different feedstocks

    E. Technological and economic assessments of gasifiers

    F. End-use applications

    G. State-of-the-art gasification

H. Research programs

NOTE: The LOTUS 123 Program described in Appendices C and D
may be borrowed from DNRC. Contact: Georgia Brensdahl, DNRC,
1520 East Sixth, Helena, MT 59620 or phone: (406) 444-6697.